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Popular Article

Primary and Secondary Nutrients-a Boon to Defense System against Plant Diseases

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Abstract

Plant diseases are one of the major limiting factors to shrink agricultural production and farmers use high amounts of toxic chemicals to control plant diseases, unaware of the fact that balanced nutrition can check diseases to an extent. Plant nutrients 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, particularly with regard to mineral nutrient uptake, assimilation, translocation, and utilization. They may also interfere with translocation or utilization of nutrients, inducing nutrient deficiencies or toxicities. The resulting deficiencies may lead to secondary infections by other pathogens. Ionomics, emerged as the study of the ionome (mineral nutrient and trace element composition representing inorganic component of cell), depends on the growth, physiology and genetic modifications of the plant cells. Nutrients are essential for the metabolism of crop plants hence growth and yield as well as can be considered as an important component in plant-disease interactions. Because of the complex interaction between disease, nutrient and environment, vivid information is required about how a particular nutrient is actually working in crop plants to develop a strong defense system. Knowledge on plant nutrition thus deserves a priority for disease management as a part of integrated crop production system, because balanced nutrient supply ensures optimal plant growth and is usually considered optimal for disease resistance as well. Thus, this article focuses on the information regarding management of plant diseases (fungal, bacterial and viral) by balanced application of nutrients with a special emphasis to primary (N, P, K) and secondary (Ca, Mg, S) nutrients.

1. Introduction

The importance of sustainable agriculture has risen to become one of the most important issues in agriculture. In addition, plant diseases continue to play a major limiting role in agricultural production. The control of plant diseases using pesticides raises serious concerns about food safety, environmental quality and pesticide resistance, which have dictated the need for alternative pest management techniques (Dordas, 2009). So finding out the alternate management system to increase tolerance level is more pertinent. Sustainability in agriculture is partially dependent on disease resistance of crops grown. Role of nutrients is undoubtedly important for developing a sound defense system among plants.Essential plant nutrients always do have some impact on the health of plants and their susceptibility to disease. Plants suffering a nutrient stress will be more susceptible to diseases, while adequate crop nutrition makes plants more tolerant of or resistant to disease. The resistance of plants to diseases is mainly related to genetics. However, the ability of the plant to express its genetic resistance to a particular disease is affected by mineral nutrition. Some nutrients have a greater impact on plant diseases than others. However, it should be noted that a particular nutrient may have opposite impacts on different diseases and in different environments, i.e. the same nutrient may decrease the incidence of one disease, but increase the incidence of others (Agrios, 2005). Hence it's the high time to summarize the knowledge as well as update with new information generated regarding management of plant diseases by balanced application of nutrients with special emphasis to primary (N, P, K) and secondary (Ca, Mg, S) nutrients. The study of ionomics may drag special attention here as it involves both the quantitative and simultaneous measurement of the elemental composition of any living organisms (viz., plant cell). It also captures useful information about the functional state of plants driven by number of factors, like genetic and developmental differences, biotic and abiotic stresses (Salt et al., 2008).

2. Primary and Secondary Nutrients

B.J. von Liebig, a German scientist in the mid-19th century, showed that nutrients are essential for plant life. Knowing the nutrients required to grow plants is only one aspect of successful crop production. Optimum yield also requires knowing the rate to apply, the method and time of application, the source of nutrients, and how the elements are influenced by soil and climatic conditions. There are 18 nutrient elements required to grow crops. Three essential nutrients-carbon (C), hydrogen (H) and oxygen (O_2)-are taken up from atmospheric carbon dioxide and water. The other 15 nutrients are taken up from the soil and are usually grouped as primary nutrients, secondary nutrients and micronutrients.

2.1. Primary nutrients

Nitrogen (N), phosphorus (P) and potassium (K) are primary nutrients, found to be utilized in the largest amounts by crops, and therefore, are applied at higher rates than any secondary nutrients and micronutrients.

2.2. Secondary nutrients

Calcium (Ca), magnesium (Mg) and sulfur (S) are required in smaller amounts than the primary nutrients. The major source for supplementing the soil with calcium and magnesium is dolomitic lime, although these nutrients are also available from a variety of fertilizer sources. Sulfur is available in fertilizers such as potassium and magnesium sulfate, gypsum (calcium sulfate) and elemental sulfur.

3. Defense System in Plants vis-a-vis Disease Resistance

Plants contain a rich source of nutrients that indulge many bacteria, fungi, protists, insects, and vertebrates to attack. In due course of evolution, plants have developed different structural, chemical, and protein-based defenses designed to detect invading organisms and stop them before they are able to cause extensive damage. Humans depend on plants for food, and plants provide many important non-food products like wood, dyes, textiles, medicines, cosmetics, soaps, rubber, plastics, inks, and even industrial chemicals. Understanding how plants defend themselves from pathogens and herbivores is thus essential to protect ourselves in terms of food supply and also to develop disease-resistant crop cultivars.

Disease is any physiological abnormality or significant disruption in the "normal" health of a plant. Disease may either caused by living (biotic) agents, including fungi and bacteria, or by environmental (abiotic) factors such as nutrient deficiency, drought, lack of oxygen, excessive temperature, ultraviolet radiation, or pollution. In array to protect from invasion of disease causing organisms, plants have developed a wide variety of constitutive and inducible defenses. Constitutive (continuous) defenses gained by barriers like cell walls, waxy epidermal cuticles, and bark. Apart from providing protection they also impart the plant strength and rigidity. Inducible defenses subjected to the production of toxic chemicals, pathogen-degrading enzymes, and deliberate cell suicide (Freeman and Beattie, 2008).

In other sense, plants have two kinds of defenses:

• Structural Defenses: Plant Cell, plant tissues and specialized appendages

• Chemical Defenses: Plant chemicals can be divided into two major categories: primary metabolites and secondary metabolites.

These compounds usually belong to one of three large chemical classes: terpenoids, phenolics, and alkaloids. Primary metabolites are substances produced by all plant cells that are directly involved in growth, development, or reproduction. Plants usually divert a significant proportion of assimilated carbon and energy to the synthesis of organic molecules that are not directly involved in growth or reproduction but they are often involved with plant defense. These molecules are known as secondary metabolites.

Table 1: Function of essential mineral nutrients (primary and secondary) (Spann and Schumann, 2010)

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

4. Relationship of Plant Nutrition and Diseases

Plant diseases often cause a major setback to improve production efficiency and crop quality as they severely hinder nutrient uptake, distribution, and assimilation by the plant. Disease symptoms frequently reflect the altered nutritional status of the plant and hence it is difficult to distinguish. 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:

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 that provide protection against pathogens.

The availability of genetic resistance to disease has permitted the production of many crops; however, providing nutrient sufficiency continues as an important component for the full expression of genetic resistance. Many cultural disease control strategies like crop rotation, organic amendment, soil pH adjustment, tillage, and irrigation management frequently influence disease in terms of nutrient interactions. These practices mostly facilitate more nutrient availability to a plant through altered biological activity. As a rule, plants with an optimal nutritional status have the highest resistance (tolerance) to pests and diseases. Susceptibility increases as nutrient concentrations deviate from this optimum (Spann and Schumann, 2010).

5. Fungal Diseases

There is constant movement of nutrients within the cell to the apoplast (the space between plant cells) through leakage of thinner, weaker cell walls. Germination of fungal spores on leaf and root surfaces is often stimulated by this leakage. Mineral nutrient levels in plant cells hence directly influence the amount of leakage as well as the composition of leaked substances. Potassium (K) is essential for the synthesis of proteins, starch, and cellulose in plants. Cellulose is a primary component of cell walls, so 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. Nitrogen (N), on the other hand, 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. Calcium (Ca) also plays an important role to buildup sugars and amino acids in both leaf and stem tissues. In this way, 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 exhibits a close correlation between the Ca content of tissues and their resistance to fungal diseases.

6. Bacterial Diseases

Imbalanced mineral nutrition often promotes the plants to bacterial infections alike the fungal infections. If N levels are deficient, plants are more susceptible to bacterial attacks, whereas K and Ca play key roles in forming an effective barrier to infections. It was found that disease relationships to K content are more consistent. 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 over application of dolomite or magnesium lowers this resistance. Adequate N levels increase plant resistance to most bacterial diseases; however, excessive N can have the opposite effect. It was found, parasites that live on senescing (dying) tissue or that release toxins in order to damage or kill the host plants actually thrive in low N situations. But on the other hand, some bacterial population increase under high N conditions. These bacteria usually depend on food sources from living tissues. Ca compounds play an essential role in the formation of healthy, stable cell walls and an adequate level of Ca inhibits the formation of enzymes produced by both fungi and bacteria. Ca deficiencies activate the accumulation of sugars and amino acids in the apoplast, which lowers disease resistance.

7. Viral Diseases

Nutritional factors (especially N and P) equally favor the growth of host plants and virus multiplication. However, visible symptoms of the infection do not essentially appear to an increase in mineral nutrient supply to the host plant despite the rapid multiplication of the virus. Even symptoms of virus infections sometimes disappear when N supplies are large although the entire plant is infected. Visible symptoms are dependent upon the competition for N between the virus and the host cells, which is influenced by environmental factors, like temperature.

8. Soil-borne Diseases

Soil-borne fungal and bacterial diseases are affected by mineral nutrition. Nitrites (NO_2^-) are toxic to some disease causing fungi species, like *Fusarium* and *Phytophthora*, which is formed in the soil from ammonium nitrogen in the nitrogen cycle as it is converted to nitrates by beneficial soil bacteria. The use of ammonium-based fertilizers can increase the incidence of some diseases, whereas nitrate-based fertilizers generally have the opposite effect. It may happen due to 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.

9. Specific Role of Element

9.1. Nitrogen (N)

Nitrogen is the most important nutrient for plant growth and so extensively studied about its effect of N on diseases. But the effect of N is quite inconsistent as reported in the published literature. This is due to the different response depending on the type of the pathogen (Marschner, 1995). For the obligate parasites, (e.g. *Puccinia*) high N supply increases the severity of disease infection; however, in case of facultative parasites, (e.g. *Alternaria*, *Fusarium* and *Xanthomonas* spp.) high N supply decreases the severity of the infection (Dordas, 2009). It is believed that plants grown under low N availability are better defended against pathogens because of the synthesis of defense-related compounds (Hoffland et al., 2000). But the situation remains more complex for soil-borne pathogens as on the root surface there are many more microorganisms than in the bulk soil. The rate and form of N-fertilizers as well as the presence of nitrification inhibitors can affect the disease tolerance in any plants. The form of N can affect the pH of the soil which in turn controls the availability of other nutrients with residual N, time of fertilizer application, previous crop, and ratio of NH_4^+-N to NO_3^--N control disease susceptibility as a whole.

9.2. Phosphorus (P)

P is the second most important nutrient after N and is part of many organic molecules of the cell (DNA, RNA, ATP and phospholipids) that take part in many metabolic processes in the plant and also in the pathogen. Phosphate fertilization has been shown to be most beneficial when applied to control seedlings and fungal diseases, and also for root rot, soil borne diseases and virus disease for many economic and ornamental crop plants (Huber and Graham, 1999; Potash and Phosphate Institute, 1988).

9.3. Potassium (K)

K is called to be the most effective to control plant diseases and pests. As a mobile regulator of enzyme activity, K is involved in essentially all cellular functions that controls disease severity. Even proper K nutrition has been found to protect crops from nematode infections. K acts as a plant protector by altering metabolism and morphology. Nitrogen balanced with potassium is significant to disease susceptibility of plants (Dordas, 2009). K influences tissue hardening, stomatal opening patterns, etc. are closely related to infestation intensity (Marschner, 1995). It has been shown that K fertilization can reduce the intensity of several infectious diseases of obligate and facultative parasites including tikka leaf spot in peanut (Huber and Graham, 1999).

9.4. Calcium (Ca)

Ca is a structural component (as calcium polygalacturonates) of cell walls and membranes. A shortage of Ca results hence causes disruption in cell structure, so plants become less able to resist infection by causal organisms of several diseases. In addition to providing a barrier, cell walls regulate the passage of sugar and amino acids between cells (from the cytoplasm to the apoplast); but when Ca is low, it permits increased transport of sugars from within the cell to the intercellular spaces in the plant tissue which stimulate the chances of infection and growth of disease pathogens (Marschner, 1995).

It was reported that plant tissues low in Ca is also much more susceptible than tissues with normal Ca levels to parasitic diseases during storage. Adequate soil Ca is needed to protect peanut pods from infections by *Rhizoctonia* and *Pythium* and application of Ca to the soil eliminates the occurrence of the disease (Huber, 1980). Ca was also found to cause resistance against *Pythium*, *Sclerotinia*, *Botrytis* and *Fusarium* (Graham, 1983).

9.5. Magnesium and sulphur (Mg, S)

Not much information is available about roles of S and Mg in plant diseases. However, some reports were found that Mg decreases the Ca content of peanut, so predispose them to pod breakdown by *Rhizoctonia* and *Pythium* (Huber, 1980).

10. Ionomics and Monitoring of Plant Health

Though the concept of plant ionomics started in late 60's, but it gained momentum only in the last decade with the advancement of science. Significant development of plant ionomics was carried forward by Lahner et al. (2003), Leonhardt et al. (2004), Salt et al. (2008) and Fleet et al. (2011), however this particular area is still infant at this stage.

Interactions among minerals can affect the absorption and bioavailability of other nutrients occurs both in plant tissues and rhizosphere, ultimately leads to deficiency or toxicity of a particular nutrient. These imbalances not only hamper the plant growth and yield but also induce plant to be susceptible to various diseases. Minerals with similar atomic composition can compete each other in terms of uptake mechanisms and transport of proteins, thus either facilitating or hindering their absorptions in plant cells. The concentration and moreover the ratios of ions impact on the uptake and transport of a particular nutrient (Grattan and Grieve, 1998).

Ionomics not only gives a complete elemental profile of a plant cell indicating toxicity, deficiency and interaction, it also becomes essential to identify potential gene(s) responsible for the uptake, transport, and storage of ions in plant cells. It involves the measurement of elemental composition of an organism and to study their changing composition in relation to physiological, developmental, environmental, and genetic factors. It renders the functional analysis of genes and gene networks that directly or indirectly affect the whole ionome. Basically, it combines plant nutrition, physiology, genomics, metabolomics and bioinformatics to understand the overlapping relationship of gene, physiology and environmental factors on the variability of elemental composition of plant cells.

The ionome (inorganic component of cellular and organismal systems) of a plant is driven by several physiological processes, from rhizosphere to leaf-evapotranspiration and in between phloem of the shoot. Hence the shoot ionome is much sensitive to the physiology of the plant, and separate ionomic profiles may reflect the physiological states of plant. These profiles can serve as biomarkers for the present physiological condition of plants. Certainly the attack of disease causing organisms alter the plant physiology (by changing ionic ratios of cells), therefore these profiles would help to monitor plant health over growth period. Thus ionomic biomarkers, a simple yet useful way to identify if a plant started to show some disease symptoms. This is also helpful to determine if a plant suffering from cold or drought stress, perturbed cell wall or wax biosynthesis, changes in root architecture, cell wall structure etc. (Salt et al., 2008).

As ionomics study involves highly specialized, sensitive and technically-sound instrumentation, the techniques used are categorized into the following two based on available literatures (Singh et al., 2013):

(i) Techniques based on electronic properties of elements

- a) Atomic absorption spectrometry (AAS),
- b) Ion beam analysis (IBA),
- c) X-ray fluorescence spectroscopy (XRF),
- d) Inductively coupled plasma spectroscopy (ICP-MS and ICP-OES);

(ii) Techniques based on nuclear properties of elements

- a) Neutron activation analysis (NAA)
- b) synchrotron based X-ray fluorescence microscopy (SXRF)

11. Factors for Improving Plant Nutrition and Disease Resistance

Apart from application of nutrients as fertilizers, cultural factors that influence the tolerance to the disease by increase in the availability and limit the imbalance of certain elements can affect growth and the tolerance of diseases. Most of the approaches that are used in sustainable agriculture have been found to provide a balanced plant nutrition, and at the same time to increase the availability of certain elements and improve the tolerance of plants to diseases (Dordas, 2009). Some of them are:

- Application of soil organic matter
- Crop rotation, cover crops, and Intercropping
- Soil Tillage

12. Nutrient Management to Control Diseases

Manipulating the various interactions of the plant, pathogen, and environment over time can reduce most diseases. Considerations can be given to nutrient availability relative to plant needs (deficiency, sufficiency, excess), in terms of the rate, time and method of nutrient application, nutrient balance and associated ions, and integration of fertilization with other crop production practices. Mineral nutrients are applied to meet the potential needs for efficient crop production so that the crop can be raised most economically. The greatest disease responses are observed when going from deficiency to plant sufficiency; however, the needs and uptake of nutrients depend on the factors like i) stage of plant growth ii) availability of nutrients in the soil iii) time of application iv) microbial activity, as well as general health of the plant. The time of fertilization should be maintained to minimize periods of irreversible nutrient deficiency without stimulating pathogenic activity (Huber and Haneklaus, 2007). Nutrient imbalance may be another detrimental factor that tolls on plant growth and disease resistance. Potassium plays an important role such that ratio of each element rather than the actual amount of either element individually contribute to diseases resistance (Huber, 1980).

13. Conclusion

Disease resistance of any plant is genetically controlled but interrelated with the nutritional status of the plant or pathogen and thus nutrient management is an important regulator for plant disease. The close relationship of the plant's nutritional status with pathogens and the abiotic environment is dynamic and hence severity of most diseases can be greatly decreased by proper nutrient management. The nutritional status of a plant also determines its histological or morphological structure and properties, which in turn controls the entry of pathogen, rate of penetration and pathogenesis.

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