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Role of Mineral Nutrition in Plant Disease Resistance

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Plants are composed of different types and kinds of organic compounds such as carbohydrates (sugars, lipids, fats, oils), proteins, hormones, vitamins, and nucleic acids (DNA and RNA). Organic compounds are biochemically synthesized from various elements held together by chemical bonds. So far 17 essential elements have been identified in high plants (Table1). Out of these 17 elements, the first eight are called trace or micronutrients and t he last nine are known as major or macronutrients. A micronutrient is one whose concentration is equal to or less than 100 mg/kg of dry matter of plant tissues, and a macronutrient is one whose concentration is equal to or greater than 1000 mg/kg of dry matter. The availability of these elements in relevant proportions and at the right stage of plant development is very important for plant health. Lack of one or more of these elements can lead to abiotic or nonparasitic disorders and/or biotic or parasitic diseases. Both types of disorders impair the normal functioning of the plants leading to a decrease in quality and quantity of produce.

Initially it is difficult to differentiate between the abiotic and biotic symptoms because both show tissue discoloration. As the symptoms advance, abiotic disorders display gradations in color change followed by drying and crumbling of the tissues. Biotic symptoms eventually turn into disease like conditions such as spoiling, wilting, and decaying of the plant tissues.

TABLE 1: Essential Elements for Most Higher Plants and Internal Concentrations Considered Adequate.

Element	Chemical Symbol	Form Available to Plants*	Concentration in Dry Tissue mg/kg	(%)
Molybdenum	Mo	MoO_4^{2-}	0.1	0.00001
Nickel	Ni	Ni^{2+}	?	?
Copper	Cu	**Cu^{2+}**, Cu^{+}	6	0.0006
Zinc	Zn	Zn^{2+}	20	0.0020
Manganese	Mn	Mn^{2+}	50	0.0050
Boron	B	H_3BO_3	20	0.002
Iron	Fe	**Fe^{2+}**, Fe^{3+}	100	0.010
Chlorine	CI	CI-	100	0.010
Sulfur	S	SO_4^{2-}	1,000	0.1
Phosphorus	P	**$H_2PO_4^-$**, HPO_4^{2-}	2,000	0.2
Magnesium	Mg	Mg^{2+}	2,000	0.2
Calcium	Ca	Ca^{2+}	5,000	0.5
Potassium	K	K^+	10,000	1.0
Nitrogen	N	**NO_3^-**, NH_4^+	15,000	1.5
Oxygen	O	O_2,H_2O	450,000	45
Carbon	C	CO_2	450,000	45
Hydrogen	H	H_2O	60,000	6

*The more common of two forms is indicated by **boldface** type.

Abiotic or Nonparasitic Disorders and Nutrients

Symptoms in the plant tissue caused by the lack or excess of essential nutrients, without the presence of pathogens, are called abiotic or non-parasitic disorders. Deficiency may occur due to the non-availability of an element or because of an interaction between different elements. Identification of nutrient deficiency is also complicated because some element may cause different symptoms in different crops or different elements may induce similar symptoms on the same plant species. Also, a given element may induce different symptoms under variable environmental conditions on different plants. For example, iron and manganese deficiency results in a similar chlorosis of foliar tissues in wet and alkaline soils. Similarly, nitrogen and sulfur deficiencies may cause similar chlorosis on plant tissue. Pathogens can also cause mineral deficiencies. For example, *Fusarium* and *Verticillium* wilts of many crops, can immobilize manganese and iron in the rhizosphere (the region of soil closely surrounding the plant roots). Thus creating abiotic symptoms usually caused by iron and manganese deficiencies.

Abundance of a specific element is as damaging as its deficiency. For example, when aluminum is present in excess in acidic soils,

Table 2: Nutrient Deficiency and Plant Symptoms

Element	Plant Species	Symptoms
Nitrogen	Corn	Yellowing of leaves and firing of tips. Yellowing creates "V" shaped pattern down midrib.
Nitrogen	Alfalfa	Plants become dwarf and spindly showing light green color. Initially pink color stars in the petioles of older leaves which continues underside up on the midrib.
Nitrogen	Strawberry	Old leaf margins become orange/red and young leaves pale green with shortened petals.
Nitrogen	Sugar beet	Light green chlorosis on leaves.
Phosphorus	Corn	Stunted plants with purple coloration at leaf margins.
Phosphorus	Potato	Stunted plants with darker green leaves, leaves roll upward.
Phosphorus	Strawberry	Older foliage turn purple, and root system becomes smaller.
Phosphorus	Alfalfa	Stunted top growth showing stiff and erect posture. Leaves become smaller, fold together and develop blush green color. Underside stems may show reddish or purplish coloration.
Potassium	Corn	Leaf margins develop yellow color followed by dying of leaf margins.
Potassium	Grapes	Yellowing to bronzing of lead margins and increasing inward between the veins. Downward curling of leaves.
Potassium	Alfalfa	Tapering of white spots (freckles) at the margins of the lower leaflet. Areas between the spots turn yellow and leaves die. Gray spots on the upper surface of older leaves which become pinkish cinnamon.
Potassium	Strawberry	Older leaves show marginal necrosis, leaflet petioles become necrotic and leaflets darken, fruits may soften.
Sulfur	Corn	Young plants become stunted and intervenes show yellowish color.
Sulfur	Strawberry	Red speckling of leaves which turn pale yellow or reddish.
Sulfur	Alfalfa	Leaves and veins become pale green to yellow; yellowing is more evident on younger leaves. Plants become more stunted and unthrifty.
Sulfur	Cotton	Yellowing of top leaves while lower leaves remain green.
Calcium	Tomato	Dying of terminal buds and breaking down of fruits at the end of blossom.
Calcium	Alfalfa	Sudden collapse of petioles on younger leaves. Their undersides become reddish purple, immature leaflet tips show marginal blue-green necrosis become later gray-white. Upper true stems may collapse.
Calcium	Strawberry	New leaf tips turn brown, appear cuplike and fail to expand, interveinal necrosis appear on leaves. Softening of fruits.
Magnesium	Citrus	Chlorosis of tips and margins of mature leaves. Produce "Christmas tree" like pattern along midrib. Upward curling of leaves along margins.
Magnesium	Strawberry	Interveinal areas of older leaves turn yellow or red and become necrotic.
Magnesium	Alfalfa	Lower leaves show interveinal chlorosis, initially margins remain green but later become chlorotic and die. Margins of older leaves become reddish, color extends into the center of lamina, forming a V-shaped green tissue around the base of midris.
Boron	Alfalfa	Upper leaves develop yellow or reddish yellow color. Internodes at the top become shorter creating a "rosetta" appearance. Leaflet margins and undersides of youngest leaves develop purplish to rose pink color. Later chlorosis extends to interveinal tissue and upper leaf surface becomes yellow to reddish yellow.
Boron	Strawberry	Plants produce deformed berries and asymmetrical leaves with stubby roots.

toxicity becomes more damaging to the crop. A severe imbalance of some of the essential nutrients may also make the plant to take excessive amounts of another nutrient. For example, excessive accumulation of ammonia-nitrogen (NH_4-N) by tobacco plants growing in fumigated soils restricts photosynthesis. This type of toxicity can be avoided by the use of nitrate-nitrogen (NO_3-N). The underlying cause of ammonia-nitrogen is inherent in microbial interactions in the soil. In fumigated soils, remnants of nitrogen-cycle bacteria respond differently to the compounds of a nitrogen source. When ammonia is supplied, the population of *Nitrosomonas* bacterial species recovers more rapidly than the *Nitrobacter* bacterial species and convert ammonia into nitrite-nitrogen (NO_2-N) which is toxic to the plants. *Nitrobacter* species are needed to convert nitrite-nitrogen into nitrate-nitrogen which is a useful nitrogen source for plants.
Contrarily, microbes can also induce deficiency. Gray-speck disease of oats is caused by manganese-oxidizing bacteria growing in the rhizosphere of susceptible oat plants; resistant oat plants inhabit these bacteria and thus avoid deficiency. Nitrogen deficiency can also be induced during microbial decomposition of carbonaceous residues in the soil. Other microbes can actually balance the nutrient deficiencies. Nitrogen fixing bacterial species (*Rhizobium*) of leguminous plants fix atmospheric nitrogen and plants in turn provide carbohydrates for the bacteria. *Mycorrhizae* fungi increase absorption of phosphorus, potassium and nitrogen by the plants. Some of the examples of abiotic disorders caused by nutrient deficiency are given (Table 2).

Table 2: Nutrient Deficiency and Plant Symptoms (continued)

Element	Plant Species	Symptoms
Boron	Apple	Flower parts are affected resulting in fewer flowers, lower retention, and lower pollen germination. Leaves become thickened, brittle, and growing points die.
Boron	Tomato	Chlorosis and necrosis develop on leaf margins.
Iron	Citrus	Young leaves show green veins with yellowing of interveinal areas.
Iron	Strawberry	Interveinal yellowing of younger leaves.
Iron	Alfalfa	Younger leaves first become chlorotic and then turn progressively from yellowish green to bleached yellow, veins also turn yellow and finally leaves become white.
Iron	Cherry	Younger leaves turn yellow with veins showing a network of greens on a yellow background.
Zinc	Citrus	Leaves become smaller and narrow and show yellow mottling between the veins. Younger leaves show Zinc deficiency first.
Zinc	Alfalfa	Younger leaves become smaller, stiffer, and curl upward (little leaf syndrome) older leaves develop bronze spots on the upper surface around the margins later becoming white and necrotic.
Zinc	Strawberry	Stunted plants with narrow leaves showing interveinal chlorosis.
Zinc	Cotton	Interveinal chlorosis on younger leaves. As the deficiency progresses, leaves become smaller, thick, and brittle.
Manganese	Strawberry	Leaf blades develop green marginal halo, and with age leaves show purple stripling.
Manganese	Alfalfa	Youngest leaves show reduced growth and strong interveinal chlorosis, but veins remain green. Later necrosis spreads to the entire leaf.
Manganese	Citrus	Younger leaves show interveinal chlorosis with gradation of pale green coloration showing darker green color next to the entire leaf.
Copper	Strawberry	Uneven yellowing and bleaching of leaf blades, leaves become smaller.
Copper	Alfalfa	Younger leaf petioles cause leaflets to bend back against the lower parts. Wilted leaves show white spots.
Molybdenum	Strawberry	Upward folding of leaf margins and marginal chlorosis.
Molybdenum	Alfalfa	Lower leaves drop off prematurely. Plants become stunted and pale green, leaflet show interveinal white notching followed by whitening of tips completely
Molybdenum	Citrus	Yellow spotting on younger leaves become bigger as the leaves grow older. Marginal scorching and rolling of leaves.
Chlorine	Walnut	Marginal necrosis on affected leaves.
Chlorine	Tomato	Chlorosis and necrosis of tomato leaves followed by browning of leaves.

Biotic or Parasitic Diseases and Nutrients

Parasitism on plants caused by various types and kinds of pathogens refers to the type of association in which parasites benefit at the expense of plant nutrients. A parasite grows in/on plants by utilizing nutrients that are otherwise required by the plants. Nutrients are directly involved in all mechanisms of defense in the plant. The kinds of disease symptoms produced by the deficiency of a given nutrient in a given plant tissue depends primarily on the metabolic function of that particular element. For example, in plant cell walls the role of calcium is very important because it gives strength to cells and helps meristematic tissue to grow. Cell walls are cemented together by a layer of middle lamella which is composed of pectin. With the help of calcium, pectin is converted to calcium pectate which inhibits infection by pathogenic fungi such as *Pythium* and *Fusarium* species. Deficiency of calcium enables these fungi to induce seedling diseases on tomato and onion, damping-off on pepper and sugar beet and browning root on wheat and pepper. Generally excessive nitrogen doses promote succulent tissues and luxuriant vegetative growth that promotes *Pythium* rots of wheat, sugarbeet, and tomato.

Resistance to Pathogenic diseases is a dynamic process involving various metabolites formed prior to an invasion by the pathogen. Metabolites produce mechanical barriers such as wax and crock layers in cell walls, *phytoalexins* (chemicals which are toxic to fungi) and enzymes that inhibit pathogenic infection. These inhibitory products need essential nutrients to function properly.

Overlapping of Abiotic and Biotic Symptoms

Symptoms produced by

Table 3: Increase or Decrease in Disease by Nitrogen without Reference to the Form of Nitrogen

Disease	Pathogen	Host Plant	Nitrogen
Bacterial Disease			
Leaf spot	Pseudomonas pruni		Decrease
Bacterial spot	Xanthomonas pruni		Decrease
Shot-hole	Bacterium pruni		Decrease
Blight	P.solanacearum		Decrease
Leaf blight	X.oryzae		Increase
Stewart's wilt	X.stewartii		Increase
Citrus canker	X citri		Increase
Crown gall	Agrobacterium tumefaciens		Increase
Saprophyte	A.radiobacter		Decrease
Fungus Diseases			
Club root	Plasmodiophora brassica	Cabbage	Decrease
Root rot	Phymatotrichum omnivorum	Cotton	Decrease
	Rhizoctonia solani	Many	Decrease
Sclerotium rot	Sclerotium rolfsii	Sugar beet	Decrease
Black spot	Diplocarpon rosae	Rose	Decrease
Wilt	Fusarium oxysporum	Lycopersici	Decrease
	Fusarium spp.	Tomato	Decrease
	F. oxysporum f. niveum	Watermelon	Decrease
	F. oxysporum f. vasinfectum	Cotton	Decrease
	Verticillium albo-atrum	Cotton	Decrease
Yellows	F. oxysporum f. conglutinans	Cabbage	Decrease
Root rot	Phymatotrichum omnivorum	Cotton	Increase
Root rot	R. solani	Bean	Increase
Damping-off	Pythium debaryanum	Tomato	Increase
Black root	Phoma betae	Sugar beet	Increase
Stalk rot	Diplodia zeae	Maize	Increase
Rot	Botrytis Cinerea	Apple	Increase
Stalk rot	Gibberella zeae	Maize	Increase
Black stem	Phoma herbarium var.medicaginis	Alfalfa	Increase
Leaf blight	Unlisted	Tomato	Increase
Scab	Venturia inaequalis	Apple	Increase
Cranker	Fusicoccum amygdali	Peach	Increase
Gray rot	B. cinerea	Grape	Increase
Early blight	Alternaria solani	Tomato	Increase
Wilt	F. oxysporum f. vasinfectum	Cotton	Increase
		Melon	Increase
Yellows	F. oxysporum f. conglutinans	Cabbage	Increase
Mildew	Bremia lactucae	Lettuce	Increase
Downy mildew	Peronospora parasitica	Cabbage	Increase
Virus Diseases			
Ring spot	Cherry ringspot virus	Cherry	Decrease
Virus	Cucumber virus-1	Spinach	Increase
Mosaic	Lettuce mosaic virus	Lettuce	Increase
Wilt	Tomato spotted wilt virus	Tomato	Increase
Virus	Yellow dwarf virus	Onion Tomato	Increase
Mosaic	Tobacco mosaic virus	Tomato	Increase
Insect Diseases			
Aphid	Myzus persicae	Tobacco	Decrease
Cabbage fly	Phorbia brassicae	Cabbage	Decrease
Chinch bug	Blissus leucopterus	Corn	Decrease
Fruit fly	Oscinella frit	Barley	Decrease
Mite		Bermuda gras	Decrease
Rice weevil	Sitophilus oryzae	Wheat	Decrease
Thrips	Heliothrips haemorrhoidalis	Spinach	Decrease
Aphid	Aphis gossypii	Cotton	Increase
Leafhopper	Empoasca terra-reginae	Cotton	Increase
	Castoblastis spp.	Prickly pea	Increase
Mealy bug	Pseudococcus comstocki	Apple	Increase
Gout fly	Chlorops taeniopus	Barley	Increase
Greenbug	Toxoptera graminum	Wheat	Increase
Nematode Diseases			
Nematode	Pratylenchus penetrans	Pea	Decrease
Root knot	Heterodera marioni	Cotton	Decrease
Nematode	Meloidogyne javanica	Tomato	Increase
Nematode	Aphelenchoides pruzae	Rice	Increase

lack or abundance of nutrients may overlap with those induced by various types and kinds of pathogenic organisms. The reason of similar symptomology is inherent in the facts that both impair nutrient uptake, translocation and their assimilation in plant tissues. Therefore, many of the primary and secondary symptoms associated with pathogenesis are, more or less, similar to those caused by nutrient deficiencies. For example, symptoms caused by manganese and iron deficiency in wheat are similar to those caused by wheat rusts. A potassium deficiency makes nitrogenous compounds accumulate in leaves causing necrotic leaf spots identical to those induced by foliar pathogens. Magnesium deficiency in wheat results in marginal chlorosis similar to leaf blotch usually induced by severe infection by take-all fungus.

Table 4: Increase or Decrease in Disease by Inorganic Forms of Nitrogen

Disease	Pathogen	Host Plant	Nitrate	Ammonium
Bacterial Diseases				
Angular leaf spot	Xanthomonas Malvacearum	Cotton	Decrease	
Canker	X.pruni	Peach/prune	Decrease	
	Corynebacterium	Tomato	Increase	
Southern wilt	Pseudomonas solanacearum	Tomato		Increase
Fungus Diseases				
Club root	Plasmodiophora brassica	Cabbage	Decrease	
Damping-off	Pythium ultimum	Beet	Decrease	
Seedling blight	Phizoctonia solani	Sugar beet	Decrease	Increase
Black root	Aphanomyces cochlioides	Sugar beet	Increase	Decrease
Root rot	A. euteiches	Maize/tomato	Decrease	Increase
Black root	R. solani	Sugar beet	Decrease	Increase
Root rot	Pythium spp.	Maize	Increase	Decrease
	Phytophthora	Citrus	Increase	Decrease
Root rot	R. solani	Bean	Decrease	Increase
	Phymatotrichum	Cotton	Increase	Decrease
	Fusarium solani f. phaseolae	Bean	Decrease	Increase
	Fusarium spp.	Citrus	Increase	
Southern rot	S. rolfsii	Sugar beet	Decrease	Increase
Southern blight	S. rolfsii	Tomato	Decrease	Increase
Stalk rot	F. moniliforme	Maize	Decrease	Increase
Leaf spot	Septoria apii	Celery	Increase	
Northern leaf	Helminthosporium	Maize	Decrease	Increase
blight	Pyricularia oryzae	Rice	Decrease	Increase
Blast	Colletotrichum phomoides	Tomato	Increase	Decrease
Anthracnose	F. oxysporum f. vasinfectum	Cotton	Decrease	Increase
Wilt	F. oxysporum f. lycopersici	Tomato	Decrease	Increase
	Verticillium albo-atrum	Potato/tomato	Increase	Decrease
Virus Diseases				
Virus	Potato virus X	Potato		Decrease
Nematode Diseases				
Cyst nematode	Heterodera tabacum	Tobacco		Decrease
Cyst nematode	Heterodera glycinae	Soybean	Increase	Decrease
Root knot	Meloidogyne incognita	Lima bean	Increase	Decrease

Role of Individual Nutrients in Disease

Nitrogen

Nitrogen is the fourth abundant elements in plants (the first three are carbon, hydrogen, and oxygen, which are building blocks of carbohydrates). It promotes plant growth by adding to cell number and size in the tissue. It is essential for synthesis of amino acids, proteins, growth hormones and protoplasm. Because of its major role in rapid plant growth and production of excessive succulent tissue, it weakens the mechanical strength of cell walls. As a result, foliar pathogens find easy entry into the plants. But at the same time root pathogens are dislodged because vigorous root growth of seedlings escape them.

Nitrogen is assimilated both as a cation in the form of ammonia (NH_4^+) and as an anion in the form of nitrate (NO_3^-). The form of nitrogen may influence disease severity (Table 3) in association with the factors such as temperature, soil pH, microorganisms and other elements. Ammonia increases damping-off of lettuce, beans, and sugar beets (black rot) caused by *Rhizoctonia solani* by increasing the production of glutamine and asparagine amino acids unitized by the fungus to grow. Ammonia also increases the production of extra-cellular enzymes (pectinase, cellulose) which weakens the cell wall strength and thus encouraging *Rhizoctonia* and *Fusarium* root rots. On the other hand nitrate inhibits the production of these enzymes resulting in reduction of root rots.

Nitrogen in association with other elements may influence diseases. Ammonium sulfate and ammonium chloride in association with potassium chloride decrease stalk rots caused by *Diplodia zeae*, whereas similar rates of potassium nitrate increase stalk rots. Nitrate-nitrogen reduces northern corn blight if applied with potassium sulfate but increases disease if applied with potassium chloride. Chloride fertilizers inhibit nitrate uptake.

Time of application of nitrogen sources is also important in diseases. For example, *Verticillium* wilt infects the plants early in season, yet visible symptoms appear when plants start fruiting. Ammonia, by delaying plant maturity reduces *Verticillium* wilt while nitrate-nitrogen hastens the maturity and enhances wilt severity. Increasing level of nitrate-nitrogen during fruiting in tomato, cotton, and pepper increases *Verticillium* wilt. In comparison, *Fusarium* wilts of cotton, tomato, pea, and cabbage yellows decrease with increase in nitrate-nitrogen. Temperature may play a role in *Fusarium* wilts. Increasing severity of rice blast fungus with ammonia-nitrogen is associated with low temperature (68F) because ammonia increases amide nitrogen levels in plant tissue which induces fungal growth.

Phosphorus

Phosphorus is known to decrease seedling diseases by enhancing vigorous root growth. Diseases such as *Thielavia* root rot of tobacco, *Septoria* leaf spot of tomato, eye spot of sugar

Table 5: Increase or Decrease in Disease by Phosphorus

Disease	Pathogen	Host Plant	Phosphorus
Bacterial Diseases			
Blight	Pseudomonas syringae	Lima bean	Decrease
Fireblight	Erwinia amylovora	Apple/pear	Increase
Stewart's wilt	Xanthomonas stewartii	Maize	Increase
Fungus Diseases			
Damping-off	Rhizoctonia solani	Pea/cucumber	Decrease
Root rot	Gibberella saubinetti	Corn	Decrease
	R. solani	Soybean	Decrease
Rot	Phoma spp.	Beets	Decrease
Stalk rot	Gibberella zeae	Maize	Decrease
Leaf blight		Tomato	Decrease
Leaf spot	Septoria spp.	Tomato	Decrease
Early blight	Alternaria solani	Tomato	Decrease
Wilt	F. lycopersici	Tomato	Decrease
	F. vasinfectum	Cotton	Decrease
Downy mildew	Peronospora parasitica	Cabbage	Decrease
	Plasmopara viticola	Grape	Decrease
Club root	Plasmodiophora brassicae	Cabbage	Increase
Root rot	Phymatotrichum omnivorum	Cotton	Increase
	Thielaviopsis basicola	Citrus	Increase
Stalk rot	Diplodia zeae	Maize	Increase
Stem rot		Rice	Increase
Yellows	F. oxysporum f. conglutinans	Cabbage	Increase
Wilt	F. oxysporum f. vasinfectum	Cotton	Increase
	F. oxysporum f. lycopersici	Tomato	Increase
Downey mildew	Plasmopara viticola	Grape	Increase
Mildew	Bremia lactucae	Lettuce	Increase
Virus Diseases			
TMV	Tobacco mosaic virus	Tomato	Increase
Virus	Cucumber virus-1	Spinach	Increase
Yellow mosaic	Yellow tobacco mosaic virus	Tobacco	Increase
Nematode Diseases			
Root-knot	Meloidgyne incognita	Pea	Increase
Insect Diseases			
Aphid	Myzus persicae	Tobacco	Increase
Frit fly	Oscinella frit	Barley	Decrease
Leafhopper	Empoasca terra-reginae	Cotton	Decrease

Table 6: Increase or Decrease in Disease by Potassium

Disease	Pathogen	Host Plant	Potassium
Bacterial Diseases			
Bacterial blight	Pseudomonas syringae	Lima bean	Decrease
Angular leaf spot	P. lachrymans	Cucumber	Decrease
Angular leaf	Xanthomonas malvacearum	Cotton	Decrease
Stewart's wilt	X. stewartii	Maize	Decrease
Bacterial blight	X. oryzae	Rice	Decrease
Soft rot	Erwinia carotovora	Cabbage	Decrease
Fire blight	E. amylovora	Pear	Decrease
Bacterial wilt	E. tracheophilla	Cucumber	Increase
Fire blight	E. amylovora	Apple/pear	Increase
Canker	Corynebacterium michagense	Tomato	Increase
Fungal Diseases			
Damping-off	Pythium ultimum	Beef	Decrease
	Gibberella saubinetti	Maize	Decrease
	Phymatotrichum omnivorum	Cotton	Decrease
Stalk rot	Fusarium moniliforme	Maize	Decrease
Stem rot	Leptosphaeria salvinii	Rice	Decrease
Stem end rot	Fusarium spp.	Potato	Decrease
Leaf blight	Helminthosporium turcicum	Maize	Decrease
Northern leaf blight	Helminthosporium turcicum	Maize	Decrease
Brown spot	Helminthosporium spp.	Rice	Decrease
Stem rot	Helminthosporium sigmoidum	Rice	Decrease
Blast	Pyricularia oryzae	Rice	Decrease
Yellows	Fusarium oxysporum f. conglutinans	Cabbage	Decrease

cane, downy mildew of cabbage and *Gibberella* root-rot of corn are reduced by phosphorus fertilizers. In contrast, phosphorus increases diseases that are permanent residents of garden soil because it reduces the acidity of plant tissue and enables the fungus to survive.

Phosphorus enhances the utilization of carbohydrate (sugars) during fruit and seed formation and thus shortens the vegetative growth which reduces the chances of infection by foliar pathogens. This would imply that it counteracts the effect of high levels of nitrogen. In association with potassium, phosphorus strengthens sclerenchyma cells of live plant, thereby inhibiting the penetration of foliar fungal pathogens. Phosphorus and nitrogen together increase rice yield but at the same time increase stem rot (*Sclerotium oryzae*).

Potassium

Potassium is not a structural part of plant tissue, however, its role in regulation of metabolic activities in the cell is well documented. It catalyzes many enzyme actions, Potassium is essential for translocation of sugars and for starch synthesis. It encourages root growth, and produces uniformity in size of the xylem vessel for efficient water transport.

Potassium fertilizers are usually used to reduce

Table 6: Increase or Decrease in Disease by Potassium (continued)

Disease	Pathogen	Host Plant	Potassium
Wilt	Fusarium oxysporum f. lycopersici	Tomato	Decrease
	Fusarium oxysporum f. vasinfectum	Cotton	Decrease
Wilt	F. oxysporum f. melonis	Melon	Decrease
Mildew	Phyllactinia guttata	Rose	Decrease
	Bremia lactucae	Lettuce	Decrease
Club root	Plasmodiophora brassicae	Cabbage	Increase
Scab	Streptomyces scabies	Potato	Increase
Root rot	Phizoctonia solani	Bean	Increase
Brown rot gummosis	Phytophthora parasitica	Citrus	Increase
Leaf blight	Fungal	Tomato	Increase
Wilt	Fusarium oxysporum f. niveum	Watermelon	Increase
	Fusarium oxysporum f. lycopersici	Tomato	Increase
Downy mildew	Peronospora parasitica	Cabbage	Increase
Virus Diseases			
Blotchy ripening	Tobacco mosaic virus	Tomato	Decrease
Mosaic	Tobacco mosaic virus	Bean	Decrease
Yellow Mosaic	Yellow tobacco mosaic	Tobacco	Decrease
Mosaic	Potato mosaic virus	Potato	Decrease
TMV	Tobacco mosaic virus	Tomato	Increase
Virus	Cucumber virus-1	Spinach	Increase
Nematode Diseases			
Nematode	Heterodera schachtii	Sugar beet	Decrease
White tip	Aphelenchoides oryzae	Rice	Increase
Root-knot	M. incognita	Cucumber	Increase
Insect Diseases			
Aphid	Aphis rumicis	Beans	Increase
Leafhopper	Empoasca terra-reginae	Cotton	Decrease

Table 7: Increase or Decrease in Disease by Calcium

Disease	Pathogen	Host Plant	Calcium
Bacterial Diseases			
Wilt	Pseudomonas caryophylli	Carnation	Decrease
Soft rot	Erwinia carotovora	Cabbage	Decrease
Bacterial blight	Xanthomonas malvacearum	Cotton	Increase
Fungal Diseases			
Club root	Plasmodiophora brassicae	Cabbage	Decrease
Damping-off	Phizoctonia solani	Soybean	Decrease
Root rot	Aphanomyces cochlioides	Pea	Decrease
Brown rot gummosis	Phytophthora parasitica	Citrus	Decrease
Root rot	Rhizoctonia solani	Bean	Decrease
	Fusarium solani	Citrus	Decrease
	Phizoctonia solani	Many	Decrease
Southern blight	Sclerotium rolfsii	Tomato	Decrease
		Pepper	Decrease
Leaf spot	Septoria spp.	Celery	Decrease
Chocolate spot	Botrytis fabae	Broad bean	Decrease
Wilt	Fusarium oxysporum f. vasinfectum	Cotton	Decrease
	Fusarium oxysporum f. lycopersici	Tomato	Decrease
	Fusarium oxysporum f. niveum	Muskmelon	Decrease
Scab	Streptomyces scabies	Potato	Increase
Damping-off	Phizoctonia solani	Cotton	Increase
Root rot	Phymatotrichum omnivorum	Cotton	Increase
Wilt	Fusarium spp.	Cotton	Increase
	Verticillium albo-atrum	Cotton	Increase
Mildew	Uncinula necator (oidium)	Grape	Increase
Virus Diseases			
Mosaic	Tomato mosaic virus	Tomato	Decrease
Nematode Diseases			
Stem nematode	Ditylenchus dipsaci	Alfalfa	Decrease

many diseases such as *Fusarium* wilt of tomato, blast (*Pyricularia*) of rice, bacterial angular leaf spot of cucumber, and stalk rot of corn. Corn, deficient in potassium, accumulates inorganic nitrogen in tracheal sap and this increases Stewart's bacterial wilt. Potassium deficiency also predisposes corn to root-rot because of accumulation of iron in corn nodes which interfere with nutrient translocation from shoot to root. Potato tubers sufficient in nitrogen and phosphorus but deficient in potassium become susceptible to late blight (*Phytophthora infestans*). Nitrogen potassium ratio is very important in plant disease control.

Potassium fertilizers are usually recommended to reduce diseases. Potassium chloride, ammonium sulfate, and ammonium chloride reduce stalk rots in corn whereas potassium nitrate increases disease severity. The reduction of stalk rot with potassium chloride is dependent on the competitive inhibition of nitrate-nitrogen uptake by the chloride ions. High rates of nitrate-nitrogen may overcome chloride in competition and this increases stalk rots.

Table 8: Increase or Decrease in Disease by Sulfur

Disease	Pathogen	Host Plant	Effect of Sulfur
Bacterial Diseases			
Stewart's wilt	Erwinia stewartii	Maize	Decrease
Fungus Diseases			
Scab	Streptomyces scabies	Potato	Decrease
Root rot	Phizoctonia solani	Soybean	Decrease
Leaf spot	Ramularia beticola	Sugar beet	Decrease
Stem rust	Puccinia graminis	Cereal	Increase
Virus Diseases			
Mosaic	Tobacco mosaic virus	Nicotiana glutinosa	Decrease

Table 9: Increase or Decrease in Disease by Magnesium

Disease	Pathogen	Host Plant	Magnesium
Bacterial Diseases			
Blight	Xanthomonas malvacearum	Cotton	Decrease
Fungal Diseases			
Club root	Plasmodiophora brassicae	Cabbage	Decrease
Damping-off	Rhizoctonia solani	Cotton	Decrease
	Helminthosporium spp.	Rice	Decrease
Wilt	Verticillium albo-atrum	Cotton	Decrease
	Fusarium oxysprorum f. conglutinans	Cotton	Decrease
Root rot	Phymatotrichum omnivorum	Cotton	Increase
Southern leaf	Helminthosporium maydis	Maize	Increase
Stem rust	Puccinia graminis	Cereals	Increase
Insect Diseases			
Purple scale	Insect	Citrus	Increase

Table 10: Increase or Decrease in Disease by Other Micronutrients

Disease	Pathogen	Host Plant	Iron	Zinc	Boron
Fungus Diseases					
Root rot	Fusarium culmorum	Cereal	Decrease	Decrease	
	Helminthosporium sativum	Cereal	Decrease	Decrease	Decrease
Stem canker	Rhizoctonia solani	Potato/bean		Decrease	Decrease
Late blight	Phytophthora infestans	Potato		Decrease	Decrease
Leaf spot	Helminthosporium spp.	Rice/cereal	Decrease	Decrease	Decrease
	Cercospora spp.	Sugar beet	Increase	Increase	
Wilt	F. oxysporum f. vasinfectum	Cotton	Increase		
Rust	Puccinia spp.	Wheat/cereal	Increase	Increase	Decrease
Virus Diseases					
Mosaic	Tobacco mosaic virus	Tobacco	Decrease	Decrease	
Insect Diseases					
Root borer	Insect	Sugar beet	Decrease	Decrease	

Calcium

Calcium is an essential component of cell walls and enhances cell division and development. It influences plant diseases by producing pectate (cell wall material) which protects the cell wall from the dissolving action of fungal extracellular enzymes. Also, calcium reduces low soil pH (acidity) and this controls disease development by enhancing cell growth and division. Plants deficient in calcium are susceptible to *Rhizoctonia solani* because of a weak cell wall, large intercellular spaces and reduced size of middle lamella (Cementing material between adjacent cells). Calcium fertilizers increase tomato resistance to diseases such as *Rhizoctonia solani* (rot), *Erwinia* (spot rot) and *Sclerotium rolfsii* (southern blight). Appropriate calcium: magnesium ratio is very important for soil fertility to produce

Botrytis spp. in many plants are the result of maturative enzymes produced by the fungi. These enzymes dissolve cell wall pectate and make fungal entry possible. But high levels of calcium and magnesium in plant tissues prohibit this enzymatic action. Liming is often thought to increase the soil pH but it also influences resistance by increasing the calcium contents of potato tubers and as a result they show resistance to streptomyces scab. Similar effects are produced by amending soil with calcium carbonate and calcium sulfate.

Other Nutrients

Silicon: It affects the availability of potassium and thus enhances the cell wall strength. Silicon contents of rice and wheat are responsible for resistance to blast (*Pyricularia oryzae*) and powdery mildew (*Erysiphe graminis*).

Iron, Zinc, and Manganese: These elements inhibit the production of proteolytic enzymes in fungi that dissolve cell wall pectin. (e.s. Fusarium spp.) and thus reduce incidence of disease.

Conclusions

Plant nutrition is largely responsible for disease control. Manipulation of plant nutrition is crucial to enhance genetical, chemical, or biological control of many types and kinds of pathogens. Although genes for resistance play a major role in determining resistance in plants, their metabolic functions are mediated by the nutrients available in balanced proportion and at different stages of plant growth. The greatest advantage from nutrition has been observed in healthy plants. Diseases caused by partially resistant varieties.

Nutrition is responsible for structural and biochemical resistance mechanisms in plants. Structural defense mechanisms are inherent in outer cell walls which are first defense road blocks for pathogen entry. Cell walls are composed of complex celluloses and semi celluloses imbedded with calcium. Thicker and healthier cell walls will impose difficulty for pathogen entry. Biochemical mechanisms are mediated by nutrients in the form of enzymes that keep the plant metabolism active. For example nitrogen is an essential part of all enzymes. If nitrogen deficiency occurs, functioning of biochemical pathways will be influenced.

Interaction of given nutrients may increase of decrease disease. Briefly, the nature of calcium: magnesium ratio, nitrogen: potassium ration, and nitrogen: phosphorus ratio influence diseases. Fertilizers that promote cell growth and division are needed during the vegetative growth of the plant. For example, nitrogen, calcium, and phosphorus compounds enhance cell division and growth. During pollination and fruit development stages phosphorus and potassium based compounds are required.

Liquid and granulated forms of fertilizers influence plant disease. Liquid fertilizers are readily taken up by plants as compared to the granulated fertilizers. Since they are relatively chemically pure and contain less salts and heavy metals, liquid fertilizers become readily available to the plant. Therefore, application of liquid fertilizers can be made at the right stage of plant growth when a particular disease incidence is apparent. Granulated fertilizers are not readily available and usually contain impurities, therefore, may not control the diseases efficiently in time.

Table 11: Increase or Decrease in Disease by Other Elements

B=bacteria; F=fungus; V=virus

Element	Disease	Pathogen	Host Plant	Effect of Element
Molybdenum	Bacterial (B)	Unknown	Lucerne	Decrease
Molybdenum	Mosaic (V)	Tobacco mosaic virus	Tobacco	Decrease
Aluminum	Root rot (F)	Aphanomyces cochlioides	Pea	Decrease
Cadmium	Powdery mildew (F)	Erysiphe graminis	Wheat	Decrease
Cobalt	Stem rust (F)	Puccinia graminis	Wheat	Decrease
Chloride	Stem rot (F)	Diplodia zeae	Maize	Decrease
Carbonate	Club root (F)	Plasmodiophora brassicae	Cabbage	Decrease
	Root rot (F)	Phymatotrichum omnivorum	Cotton	Decrease
Lithium	Powdery mildew (F)	E. cichoracearum	Cucumber	Decrease
	Stem rust (F)	Puccinia graminis	Wheat	Decrease
	Club root (F)	Plasmodiophora brassicae	Turnip	Decrease
Nickel	Stem rust (F)	Puccinia graminis	Wheat	Decrease
Trace Elements				
Trace	Bakannae disease (F)	Fusarium moniliforme	Rice	Decrease
Silver	Mosaic (V)	Tobacco mosaic virus	Bean	Decrease