Spectrum Analytic, Inc.

THE RELATIONSHIP BETWEEN NUTRIENTS and OTHER ELEMENTS To PLANT DISEASES

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Introduction

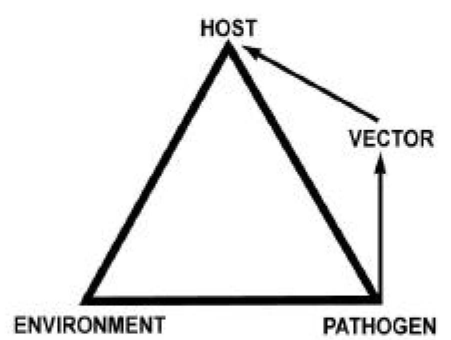
Interactions between plants, nutrients, and disease pathogens are very complex and not completely understood. Nutrition, although frequently unrecognized, has always been a primary component of disease control. Most soils and environments where plants are cultivated contain an abundance of disease pathogens. On the most basic level, plants suffering a nutrient stress will be less vigorous and more susceptible to a variety of diseases. In this respect, all nutrients affect plant disease. However, some nutrient elements have a direct and greater impact on plant diseases than others. This paper discusses the more significant nutrients and their interactions with disease.

Disease resistance in plants is primarily a function of genetics. However, the ability of a plant to express its genetic potential for disease resistance can be affected by mineral nutrition. Plant species or varieties that have a high genetic resistant to a disease are likely to be less affected by changes in nutrition than plants only tolerant of diseases. Those that are genetically highly susceptible will likely remain susceptible with nutritional regimes that greatly improve the disease resistance in less susceptible or tolerant plants. As Dr. D. M. Huber states **"It is clear that the severity of most diseases can be reduced and the chemical, biological, or genetic control of many plant pathogens enhanced by proper nutrition".** Fertilizer recommendations are developed to optimize nutrient uptake and provide the crop with adequate nutrients for normal growth and yield. In most situations, this level of nutrients will also be sufficient to enable the crop to maximize disease resistance. However, there are cases where nutrient applications higher than needed for optimum growth can result in improved disease resistance.

Principles of Plant Infection as Related to Nutrition

In order to appreciate the effect that nutrients have on plant diseases, it is important to understand some aspects of how diseases infect and multiply within the plant host. The following comments are by no means comprehensive, but they illustrate some of the important factors that impact the interactions of nutrients and plant diseases.

All disease cycles include 3 or 4 parts, as shown in the accompanying illustration. Where all of the conditions are met, the infection occurs and the disease spreads. If any part of the cycle can be interrupted, disease can be prevented or the damage limited. Some pathogens, such as viruses require vectors, or carriers, to introduce them into the host plants. As will be discussed later, these vectors can be insects or fungus. If the activity of vector can be interrupted, the disease can be controlled without directly attacking the pathogen. Nutrients and other mineral elements can have a significant impact on all aspects of the disease cycle. It may seem extravagant to claim that mineral elements can affect the environment. However, lime and fertilizer affect the soil environment. And nutrients affect the plants ability to withstand adverse weather conditions. Therefore, this claim can be made.



Fungal Diseases

Fungal infection occurs as spores germinate on plant surfaces. As germination proceeds, the fungus must penetrate the surface (epidermal) cells, either by passing between the cells or through them. The physical resistance presented by the strength and integrity of the cell walls and intercellular spaces is the plants first line of defense. Nutrients play a major role in the plants ability to develop strong cell walls and other tissue. The germination of spores is stimulated by compounds exuded by the plants. The amount and composition of these exudates is affected by the nutrition of the plant. When plants have low levels of certain nutrients, these exudates will contain higher amounts of compounds such as sugars and amino acids that promote the establishment of the fungus.

As a plant becomes infected by a fungus, its natural defenses are triggered. The infection causes increased production of fungus inhibiting phenolic compounds and flavonoids, both at the site of infection and in other parts of the plant. The production and transport of these compounds is controlled in large part by the nutrition of the plant. Therefore, shortages of key nutrients reduce the amount of the plants natural antifungal compounds at the site of infection. Conversely, it has been observed that as the N content of many plants is increased beyond sufficient levels, or perhaps when N is out of balance with other nutrients, the production of antifungal compounds decreases. As fungi and bacteria invade the plant tissue, they release certain enzymes that dissolve parts of the plant tissue. The activity of these enzymes is inhibited by the calcium ion (Ca^{++}). As the pathogen releases enzymes that dissolve plant tissue, K is lost from the plant. The loss of K by this process further reduces the plants ability to resist disease for reasons previously mentioned.

Another plant response to infection is the formation of oxygen radicals ($O^{=}$ and OH^{-}) and hydrogen peroxide (H_2O_2). These elements and compounds can be destructive to the plants cells as well as the pathogen. This is somewhat similar to using chemotherapy for cancer in people. The cure is also damaging to the patient. It also thought that in some cases there may be over-production of these materials. In either event, some nutrients act to detoxify oxygen radicals and hydrogen peroxide, thus limiting damage to plant cells.

Bacterial Diseases

Bacterial diseases can be divided into three primary types… Leaf Spot diseases, Soft Rots, and Vascular diseases.

Leaf spot pathogens typically enter the leaf through the stoma and spread within the intercellular spaces. Since the bacteria do not penetrate the surface of the leaves, the epidermal cell structure or strength is not much of a factor. Plant resistance to bacterial spread within the leaf is closely related to the structure and strength of internal cells and intercellular space, as well as the plants ability to produce and transport antibacterial compounds. These disease-fighting mechanisms are closely related to certain nutrients.

Bacterial spread within the host plant is accomplished by the bacteria's production of enzymes that cause the decomposition of pectin (a primary structural component of plant cells). The production and activity of these pectolytic enzymes is inhibited by some nutrients. Additionally, plants suffering from low quantities of those nutrients needed to build proper cell walls and other structural tissue will be subject to greater damage from these pathogens.

Bacterial vascular diseases spread by way of the xylem (the vessels that transport water and nutrients from the roots to the leaves). Their presence leads to the formation of "slime" within the vessels, eventually blocking them and leading to wilting and the death of leaves and stems. Certain plant nutrients play a role in blocking or reducing the bacteria's ability to form this slime.

Viral Diseases

There is little data on the effects of mineral nutrition on viral diseases. Viruses live and multiply within plant cells and their nutrition is limited to amino acids and nucleotides found within the cells. Generally, nutrient conditions favorable for good plant growth are favorable for virus multiplication. In some situations, symptoms of viral diseases can be made to lessen or disappear with improved nutrition. However, this appearance does not mean that the virus is not present. For example, sugar beets with beet mild yellowing virus (BMYV) exhibit symptoms similar to Mn deficiency. When beets with both Mn deficiency and BMYV infection are foliar fertilized with Mn, the visual symptoms of both problems will lessen or even disappear completely. However, work with this combined problem found that the percent of infected plants decreased from 75% in the Mn deficient plants to 40% infection after the Mn deficiency was corrected. While this is a large decrease, there remained a significant infection in the field.

The primary vectors carrying virus to a crop are sucking insects, such as aphids, and fungi. Plant nutrition can affect both fungi and some insects, thus affecting the viruses that they may carry. It has been found that the nutrient status of a plant can affect the aphid population on plants. For example, it was found in 1965 that certain aphids tend to settle on yellow reflecting surfaces, such as chlorotic leaves caused by nutrient deficiency. Feeding intensity and reproduction by sucking insects tend to be higher on plants with higher amino acid content. This condition is typical of plants suffering certain nutrient stresses. As you will read in the section on silicon, application of this non-nutrient element has been shown to physically inhibit the feeding ability of some sucking insects like aphids. In studies with watercress, it was reported that high levels of Zn fertilization improved control of the "crook rot" fungus which is also a vector for the chlorotic leaf spot virus. Therefore, the high Zn fertilization controlled both a fungus and a virus.

Nitrogen (N)

One of the most commonly assumed relationships of N to disease is that high N rates lead to more disease. Actually, proper N nutrition, which might be higher than local practices, normally suppresses disease. Adequate N uptake is essential to the formation of various structures, proteins and enzymes needed both in growth and disease resistance. A vigorously growing plant can often offset, or "outgrow" the most damaging effects of some diseases. Conversely, it has been observed that in some plants as the N content is increased beyond sufficient levels, the amount of antifungal compounds decreases.

Feeding intensity and reproduction by sucking insects tend to be higher on plants with higher amino acid content. This condition is typical of plants with a K or Zn deficiency, or a relative excess of N compared to these nutrients. In studies with watercress, it was reported that high levels of Zn fertilization improved control of the "crook rot" fungus which is also a vector for the chlorotic leaf spot virus. Therefore, the high Zn fertilization controlled both a fungus and a virus.

Potatoes deficient in either N or P are more susceptible to early blight (Alternaria solani). However, over-fertilization with N stimulates excessive, weak vegetative growth that can increase the incidence of various diseases. Nitrogen fertilizer can reduce the incidence of "take-all" (Gaeumannomyces graminis) in barley and wheat. With take-all, it is thought that that the additional N actually increases the susceptibility of individual roots to infection. However, the extra N enables plants to produce crown roots faster that the fungus can destroy them.

However, excess N uptake can promote conditions favorable to disease and insect damage.

- Excess N may promotes succulent growth and thinner cell walls, making plants more susceptible to infection.
- Excess N may promote increased plant density, thus more humid air around the plants that can favor diseases.
- Excess N can delay maturity, thus extend the time available for infection and disease development.
- Feeding intensity and reproduction by sucking insects tend to be higher on plants with higher amino acid content. This condition is typical of plants with a K or Zn deficiency, or a relative excess of N compared to these nutrients. Since some sucking insects, such as aphids are vectors for disease, an imbalance of N can lead to greater disease problems.

There are two situations where abundant N may increase the incidence or severity of disease.

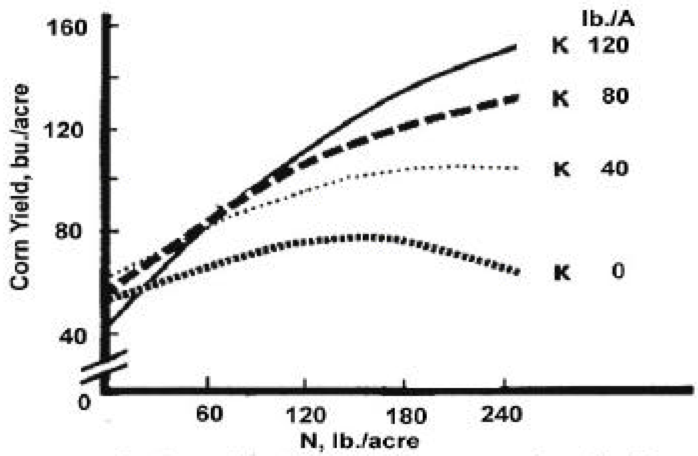
- When N availability is greater than the crops ability to efficiently use it for more growth, due to other growth limiting factors.
- When N availability is significantly greater than the availability of other nutrients. This is especially true for potassium (K) in most crops, and sometimes calcium (Ca) in fruit and vegetables.

An example of the negative effects of increased N rates was reported by Marshner. In this example, no information was given about the balance of N with other nutrients. Therefore, the increase in barley leaf blotch with N rate might have been due in part to imbalances or shortages of K or other nutrients.

N RATE and INCIDENCE of LEAF BLOTCH (Rhynchosporium scalis) in SPRING BARLEY			
N RATE (lb./A)	PERCENT INFECTION OF FLAG LEAF		
	VARIETY 1	VARIETY 2	VARIETY 3
0	0.4	15.4	3.6
59	1.3	21.3	20.5
118	4.5	30.5	57.3
Jenkyn, 1976			

The benefits of balancing N and K fertility are often a combination of improved nutrition plus disease suppression effects. The relative contribution of the dual benefits is variable. However, when N supply is out of balance with K, both yields and crop quality often suffer.

There is no defined critical N:K ratio that suppresses diseases. The growers must use proper fertilizer programs based on soil tests, plant analysis, and disease monitoring to determine the proper nutrient balance.



Optimum N rate depends on rate of applied K

In many areas where soil K is less than optimum, grain crops such as corn, wheat, barley, oats, etc. will often have less disease pressure when the fertilizer program contains K_2O rates nearly equal to N rates. Some vegetables such as tomatoes, peppers, pumpkins, and others often do best with K_2O rates that are equal to, or substantially higher than the N rate. Tree-fruit crops, such as apples, pears, cherries, and others typically require K2O rates that are much higher than the N rates. These generalities about the N:K ratio must be tempered by other soil test factors. Higher K_2O rates may depress the uptake of other nutrients such as calcium (Ca) and magnesium (Mg). Soils with a low CEC or those with inherently low Mg or Ca levels are most susceptible to these problems.

There is evidence that the form of N, or the ratio of ammonium N (NH_4-N) to nitrate N (NO_3-N) can have an effect on certain diseases in some crops.

The Effect of Delayed Nitrification on Yield and Lodging of Corn

Treatment (lb. N/A)	**Grain Yield** (bu./A)	**Lodging** (%)
120	100	39
200	126	35
120*	140	13
200*	157	14

* With nitrification inhibitor

Effect of Form of N on Plant Diseases

Crop	**Disease**	**NO_3-N**	**NH_4-N**
Corn	Stalk rot (Diplodia)	(I)ncrease	(**D**)ecrease
	Stalk rot (Fusarium)	I	**D**
	Root rot (Pythium)	I	**D**
	Northern leaf blight (Helminthosporium)	**D**	I
Soybeans	Root rot (Aphanomyces)	**D**	I
	Cyst nematode (Heterodera)	I	**D**
Wheat	Root rot (Fusarium)	**D**	I
	Take all (Ophiobolus	I	**D**
Cotton	Root rot (Phymatotrichum)	I	**D**
	Wilt (Fusarium)	**D**	I

Nitrate N can moderate the severity of black scurf (Rhizoctonia solani) in potatoes, root rots of beans and peas, and foot rot in wheat, while ammonium N aggravates these diseases. However, soil-borne pathogens such as potato scab (Streptomyces scabies) and early dying of potatoes are aggravated by NO_3-N and moderated by NH_4-N.

Some work has shown that using a nitrification inhibitor to maintain higher ratios of NH_4-N to NO_3-N has reduced the incidence of verticillium wilt, but increased the incidence of rhizoctonia canker. This may be a desirable outcome if other steps can be taken to control the rhizoctonia.

EFFECT OF INHIBITING NITRIFICATION ON DISEASE AND YIELD OF POTATO

Nitrogen Source	Verticillium Wilt[1]	Rhizoctonia Canker[2]	Yield (lb./a)	% No. 1
Ammonium Sulfate	3.9 b[3]	6.2 b	5456 b	69 b
Calcium Nitrate	9.6 a	4.8 a	3213 a	57 a

[1] Indexed on a scale of 0 – 10 where 0 = no infection, 10 = dead

[2] Indexed on a scale of 0-10 where 0=no infection, 10=complete stem girdling and death

[3] Means not followed by the same letter are significantly different at 0.05% probability

(Watson, R.D., and Huber, D.M. unpublished)

It is reported by Thor Kommedahl, in "Nitrogen in Crop Production" that for a given amount of N, deviation towards too much NH_4-N causes more disease than deviation toward too much NO_3-N.

Studies into the potential benefits of manipulating the soil NH_4:NO_3 ratio suggest that a 1:1 ratio may be desirable for optimum yield and quality of field corn and a variety of other crops. In most situations, the majority of NH_4-N in the soil will be converted to NO_3-N in a relatively short time. Therefore, NO_3-N is the predominate source of N for most crops. This can be modified somewhat by the use of nitrification inhibitors, but achieving a specific ratio of NH_4:NO_3 is difficult at best, and probably not possible on a continuing basis. If the preponderance of applied N is retained as NH_4-N, fertilizer N placement may become a concern. This is because NH_4-N is a cation and is retained on the soil CEC complex. As such, it is relatively immobile and plant roots will likely contact less of it unless it is placed in the root zone. This could have a significant effect on yields.

Potassium (K)

Of all the nutrients that affect plant diseases and pests, K is probably the most effective. As a mobile regulator of enzyme activity, K is involved in essentially all cellular functions that influence disease severity. Proper K nutrition has also been shown to help crops tolerate nematode infections with less yield loss. Dr. Noble Usherwood reported the results of an in-depth literature review of 534 references. He reported the following results.

- Potassium improved plant health in 65% of the studies and was deleterious 23% of the time (some of the deleterious effects could have been due to excess K inhibiting the uptake of Mg, Ca, and/or NH_4-N).
- Potassium reduced bacterial and fungal diseases 70% of the time, insects and mites 60% of the time, and nematodes and virus influences in a majority of the cases.
- Fungal disease infestations and yield were affected by potassium applications as follows, an average of 48% where soils tested low in potassium and 14% where soil test levels were unknown. Where soils tested low, 88% of the studies showed crop yield response to applied potassium. Crop growth responded 60% of the time where soil test levels were undefined.

SOIL K	DISEASE REDUCTION DUE TO APPLIED K	YIELD RESPONSE DUE TO APPLIED K
Low	48%	88%
Unknown	14%	60%

- Potassium's influence upon crop yield varied according to the group of pathogens involved.

PATHOGEN	YIELD/GROWTH INCREASE FROM K
Fungus	48%
Bacteria	70%
Virus	99%
Nematodes	115%
Insects, Mites	14%

- The mode of action is through plant metabolism and morphology, primarily. Accumulating nitrogen compounds, sugars, etc., are frequently accompanied by improved conditions for parasite development. Tissue hardening, stomatal opening patterns, etc. are closely related to infestation intensity.
- Crop response was not consistently different for potassium carriers.
- Nitrogen balanced with potassium is significant to disease susceptibility of plants.
- Benefits were noted more frequently in the field than in the laboratory and greenhouse experiments.

CROPS AND DISEASES WHERE POTASSIUM HAS PROVEN BENEFICIAL

This list is not necessarily all-inclusive and some pathogens may affect more plant species than those listed.

CROP	FUNGUS	PATHOGEN	CROP	FUNGUS	PATHOGEN
APRICOT	Brown rot	Sclerotinia fructocola	PEA	Wilt	Fusarium oxysporum
ASPEN	Canker	Hypoxylon mammatum	PINE	Needle shedding	?
AVOCADO	Root rot	Phytophthora cinnamomi	PINE	Wood rot	Fomitopsis annosa
BANANA	Fusarium wilt	Fusarium oxysporum	PINE, LOBLOLLY	Fusiform rust	Cronartium fusiforme
BARLEY	Net blotch	Helminthosporium teres	PINE, MONTEREY	Root rot	Phythopthora
BARLEY	Powdery mildew	Erysiphe graminis	PINE, SLASH	Fusiform rust	Cronartium fusiforme
BEET	Damping off	Phythium ultimum	PINEAPPLE	Root rot	Phytophthora cinnamomi
BERMUDA GRASS	Leaf blight	Helminthosporium cynodontis	POTATO	Late blight	Phytophthora infestans
BLUEGRASS, KY	Stripe smut	Ustilago striiformis	POTATO	Stem end rot	Fusarium spp.
CABBAGE	Gray mold	Botrytis cinerea	PRUNE	Canker	Cytospora leucostoma
CABBAGE	Yellows	Fusarium oxysporum	PUMPKIN	White mold	Sclerotinia sclerotiorum
CARNATION	Wilt	Fusarium spp.	RICE	Leaf pot	Cercospora oryzae
CELERY	Yellows	Fusarium oxysporum	RICE	Leaf spot	Helminthosporium spp.
CEREALS	Rust	Puccinia spp.	RICE	Brown leaf spot	Cochliobolus miyabeanus
CEREALS	Powdery mildew	Erysiphe graminis	RICE	Sheath blight	Corticium sasakii
CHRYSANTHEMUM	Root rot	Phoma chrysanthemicola	RICE	Stem rot	Leptosphaeria salvinii
CLOVER, RED	Wilt and Root rot	Fusarium spp.	RICE	Stem rot	Helminthosporium sigmoideum
CORN	N. Leaf blight	Exserohilum turcicum	RICE	Brown spot	Ophiobolus miyabeanus
CORN	Root rot	Gibberella saubinetti	RICE	Blast	Pyricularia oryzae
CORN	Stalk rot	Fusarium moniliforme	RICE	Stem rot	Sclerotium oryzae
CORN	Stalk rot	Gibberella zeae	ROSE	Mildew	Phyllactinia guttata
CORN	Stalk rot	Diplodia zeae	RYE	Stalk smut	Urocystis occulata
CORN	Stem rot	Fusarium culmorum	SNAPDRAGON	Wilt	Verticillium dahliae
COTTON	Root rot	Phymatotrichum omnivorum	SOYBEAN	Pod rot	Diaporthe sojae
COTTON	Wilt	Fusarium oxysporum	SOYBEAN	Purple seed stain	Cercospora kikuchii
COTTON	Wilt	Verticillium albo-atrum	SQUASH	Foot rot	Fusarium solani
COTTON	Seedling blight	Rhizoctonia solani	SUGARCANE	Eye spot	Helminthosporium sacchari
COTTON	Leaf blight	Cercospora gossypina	TIMOTHY	Leaf spot	Heterosporium phlei
COTTON	Leaf blight	Alternaria solani	TOBACCO	Leaf blight	Alternaria
FLAX	Wilt	Fusarium lini	TOBACCO	Leaf blight	Cercospora
FLAX	Rust	Melampsora lini	TOBACCO	Leaf blight	Sclerotinia
GRAPE	Fruit rot	Botrytis cinerea	TOMATO	Wilt	Fusarium oxysporum
HEMP, SUNN	Root rot	Rhizoctonia solani	TOMATO	Leaf blight	Alternaria solani
HEMP, SUNN	Root rot	Pythium butleri	TURF	Ophiobolus patch	Ophiobolus graminis
HEMP, SUNN	Root rot	Sclerotium rolfsii	TURF	Leaf spot	Helminthosporium spp.
JUTE	Anthracnose	Colletotrichum corchorum	WHEAT	Leaf blotch	Septoria tritici
JUTE	Root rot	Rhizoctonia solani	WHEAT	Glume blotch	Septoria nodorum
JUTE	Stem rot	Macrophomina phaseoli	WHEAT	Take-all	Gaeumannomyces graminis
MANGOLDS	Leaf spot	Pleospora herbarum	WHEAT	Stem rust	Puccinia graminis
MELON	Wilt	Fusarium oxysporum	WHEAT	Leaf rust	Puccinia recondita
NARCISSUS	Basal rot	Fusarium oxysporum	WHEAT	Stripe rust	Puccinia striiformis
PALM	Wilt	Fusarium oxysporum	WHEAT	Bunt	Tilletia spp.
PEA	Root rot	Aphanomyces euteiches	WHEAT	Powdery mildew	Erysiphe graminis

CROP	BACTERIA	PATHOGEN
BEAN, LIMA	Bacterial blight	Pseudomonas syringae
CABBAGE	Soft rot	Erwinia carotovora
CARNATION	Bacterial wilt	Pseudomonas cayophylii
CASSAVA	Bacterial blight	Xanthomonas manihotis
COTTON	Angular leaf spot	Xanthomonas malvacearum
CUCUMBER	Angular leaf spot	Pseudomonas lachrymans
CORN	Stewart's wilt	Erwinia stewartii
PEACH	Bacterial spot	Xanthomonas pruni
PEAR	Fire blight	Erwinia amylovora
GERANIUM	Stem rot	Xanthomonas pelargonii
RICE	Bacterial blight	Xanthomonas oryzae
TOBACCO	Angular leaf spot	Pseudomonas angulata
TOBACCO	Wildfire	Pseudomonas tabaci
TOMATO	Blotchy ripening	Erwinia herbicola
TOMATO	Wilt	Pseudomonas solanacearum
TOMATO	Graywall	Erwinia herbicola
TOMATO	Soft rot	Erwinia carotovora

CROP	VIRUS	PATHOGEN
BEAN	Mosaic	Tobacco mosaic virus
BARLEY	Barley yellow dwarf	Barley yellow dwarf virus
POTATO	Mosaic	Potato mosaic virus
POTATO	Leaf roll	Potato leaf roll virus
SQUASH	Virus	Tobacco ring spot virus
TOBACCO	Mosaic	Tobacco mosaic virus
TOBACCO	Yellow mosaic	Yellow tobacco mosaic viru
TOMATO	Blotchy ripening	Tobacco mosaic virus
CROP	**NEMATODE**	**PATHOGEN**
BEAN, LIMA	Root knot	Meloidogyne incognita
BEET, SUGAR	Nematode	Heterodera schachtii
COTTON	Reniform	Rotylenchulus reniformis
SOYBEAN	Soybean Cyst	Heterodera glycines

Obtaining disease control benefits from K can be complicated. There is little doubt that many plant species will be more susceptible to diseases if they are suffering from a K deficiency. However, little research exists that defines specific tissue K levels at which a disease is affected or the risk of infection becomes unacceptable. An additional complication is that some plants with adequate K, but excess N or P can be more susceptible to disease. The best advice is to use soil testing and plant analysis to insure that plants are receiving a balanced fertility program.

It has been known for many years that potassium contributes significantly to stalk strength in corn and other crop species.

THE EFFECT OF POTASSIUM ON CORN STALK QUALITY CHARACTERISTICS

K_2O Lb./A	Rind Thickness cm x 10^3	Crushing Strength (kg)	Dead Stalks at Harvest (%)
0	91	254	77
60	97	349	64
120	100	374	55

Nelson, W.L., 1970

Potassium also is a major factor in reducing leaf diseases. With a shortage of K the plant exudates contain higher amounts of compounds such as sugars and amino acids that promote the establishment of most fungal infections.

THE EFFECT OF POTASSIUM ON ALTERNARIA LEAF SPOT, DEFOLIATION, and COTTON LINT YIELD IN CONVENTIONAL TILLAGE AND NO-TILL CONDITIONS

	K_2O Lb./A	Alternaria[1]	Defoliation[1]	Lint Yield lb./A
Conventional Tillage	0	7.7	6.9	350
	30	5.8	4.5	556
	60	5.5	2.9	621
	120	4.7	1.3	760
No-Tillage	0	7.5	5.8	360
	30	6.1	4.2	531
	60	5.1	1.6	528
	120	4.5	0.6	669

[1] Alternaria Leaf Spot and Defoliation ratings, Tennessee

0=None, 10=Highest

Mechanism of Disease Reduction with Potassium

Potassium alters the compatibility relationship of the host-parasite environment within the plant. When a plant becomes infected by a fungus, its natural defenses are triggered. The infection causes increased production of fungus inhibiting phenolic compounds and flavonoids, both at the site of infection and in other parts of the plant. The production and transport of these compounds is controlled in large part by the general nutrition of the plant. However, K is especially critical in this role and a shortage of K reduces the amount of the plants natural antifungal compounds at the site of infection.

Potassium plays a central role in the development of thick cuticles, a physical barrier to infection or penetration by sucking insects.

Disease and parasitic infections are often more severe when there are higher levels of mineral N or sugars in a plant. An accumulation of excess mineral N or sugar is often an indication that the plant is not efficiently converting the N to proteins or the sugar to energy. Potassium plays a critical role in these processes.

The balance between K and other elements is also important. For example, Stewart's wilt in corn is known to need or benefit from higher inorganic N in the tracheal sap of the plant. Potassium deficiency reduces the ability of corn to metabolize N, thus increasing the amount of inorganic N in the tracheal sap. This increases the susceptibility to Stewart's wilt. A related mechanism has been observed for the reduction in Gibberella and Diplodia stalk rots of corn. In most plants, as inorganic N accumulates in the presence of low K levels, plant compounds that have fungicidal properties are rapidly broken down.

Increased disease resistance by different varieties of the same plant species is sometimes related to the ability of the resistant variety to take up more K. This has been seen in species as widely divergent as flax and pine trees. It was found that a naturally wilt-resistant variety of flax takes up and contains higher K levels than wilt-susceptible varieties grown under the same K fertility conditions. The resistance to Peridermium rust of some white pine varieties, while others were more susceptible, was associated with higher tissue K levels in the resistant varieties.

Potassium balance with other nutrients can also be a factor. High K uptake can be either beneficial or damaging. As stated earlier, a high N:K ratio in a plant can make it more susceptible to disease. However, other work has shown that a high K:Ca balance in some plants can lead to more disease damage. Work with potatoes and citrus trees showed that infection by common scab (Streptomyces scabies) in potatoes and Phytophthora root rot (P. parasitica) in citrus was increased by high levels of K fertilization. It was concluded in both cases that higher K uptake probably caused a shortage of Ca. The Ca shortage apparently resulted in improper formation or function of the plant cell walls, leading to increased disease infection or spread within the plants. Gall diseases can also be affected by the tissue K/Ca balance.

Feeding intensity and reproduction by sucking insects tend to be higher on plants with higher amino acid content. This condition is typical of plants with a K deficiency, or a relative excess of N compared to these nutrients. While the direct damage from these insects is important, they may also be vectors for viruses.

Many disease infections occur through open wounds and rapid healing of wounds tends to reduce infection. Work showed that grapes receiving higher K fertilization were less susceptible to Botrytis cinerea. This was attributed to more rapid healing of wounds and the accumulation of compounds toxic to the fungus around the wounds.

Adequate K nutrition can reduce the severity of nematode infection. Application of K markedly reduces damage from root knot nematodes. Work with soybean cyst nematodes shows that the severity of infection and the yield loss caused by infection are both reduced by adequate K fertilization.

		Yield Increase (bu./acre)		
			Nematicide	
Variety	**SCN Race Resistance**	**K Alone**	**Alone**	**with K**
Dare	None	6	0	13
Forest	Race 3	10	5	18
Bedford	Race 3, 4	14	4	14
Soil K: Low Missouri				

Calcium (Ca)

Calcium is a structural component of cell walls and other plant membranes. As such, it plays a major role in the integrity and function of these structures. A shortage of Ca results in plant structures that are less able to resist infection by disease organisms. Cell walls are not simply a barrier to infection. When properly functioning, cell walls regulate the passage of sugar and other compounds between cells and other plant parts. When Ca is low, it permits increased transport of sugars from within the cell to the intercellular spaces in the plant tissue. Higher sugar levels in these areas tend to increase the chances of infection and growth of disease pathogens.

RELATIONSHIP OF CATION CONTENT TO SEVERITY OF INFECTION with *Botrytis cinerea* in LETTUCE

Cation Content (%)			Infection with Botrytis*
K	Ca	Mg	
1.44	1.06	0.32	4
2.38	0.54	0.41	7
3.42	0.22	0.47	13
4.89	0.18	0.42	15

*Infection index: 0-5 slight, 6-10 moderate, 11+ severe

The proper structure and function of plant membranes is not the only role that Ca plays in reducing the occurrence or severity of diseases. As fungi and bacteria invade the plant tissue, they release pectolytic enzymes that dissolve parts of the plant tissue. This damages the plant and enhances the spread of the infection. The activity of these enzymes is inhibited by the calcium ion (Ca^{++}). As the pathogen releases enzymes that dissolve plant tissue, K is lost from the tissue, with the likely loss of the benefits that K provides.

Calcium plays a major role in improving the storage life of fleshy fruit. For example, much work has demonstrated that many apple varieties can be stored for longer periods when the fruit contains higher Ca levels. Fruit with lower Ca content tends to develop bitter-pit, which is the decomposition of the fruit tissue just under the skin. They also are more likely to turn brown and begin to decompose much sooner than fruit with high Ca content. There is also a close correlation between the Ca content of the skin of potato tubers and bacterial soft rot of the tubers caused by various species of the bacteria *Erwinia*.

As with leaf spot diseases, Ca plays a significant role with bacterial vascular diseases. The severity of many of these diseases is often proportional to the degree of Ca deficiency in the plant. The data does not indicate that excess Ca will provide additional disease prevention benefits. Bacterial spread within the leaf is closely related to the Ca content of the leaf, where deficiencies greatly increase the spread and damage from the disease. Work indicates that both resistant and susceptible varieties benefit from adequate Ca. An example of the effects of Ca can be seen with bacterial canker in tomato.

RELATIONSHIP BETWEEN Ca SUPPLY, Ca CONTENT, AND BACTERIAL CANKER IN SUSCEPTIBLE AND RESISTANT TOMATO VARITIES

	Ca Content in Tissue* (%)		Wilted Leaves (%)	
Ca Supply (ppm)	Susceptible	Resistant	Susceptible	Resistant
0	0.12	0.14	84	56
100	0.37	0.42	27	12
200	0.43	0.55	37	6
300	0.44	0.58	27	8

*NOTE: The critical Ca level for leaves of field tomatoes ranges from 1.2% to 1.5%, depending on age. Whole plant samples require a much higher Ca level

In this work it was noted that as the Ca content of the tissue increased, the K and Mg content decreased. This illustrates the antagonistic relationship between these three cation nutrients. In situations where there is a need for large applications of one or more of these nutrients, it may be expected that there will be a decrease in the uptake of the others. Where this could lead to a shortage (preferably as indicated by a plant analysis) it would be reasonable to apply a balance of the nutrient elements.

Boron (B)

Although B has been reported to reduce disease infection, or lessen its effects, its exact role is not clear. There appear to be three primary areas that are more widely accepted.

- Its role in the formation of carbohydrate-borate complexes, which control carbohydrate transport and cell wall protein metabolism.
- Its function in cell membrane permeability or stability.
- Its role in the metabolism of phenolics, and a primary role in the synthesis of lignin.

When a plant becomes infected by a fungus, its natural defenses are triggered. The infection causes increased production of fungus inhibiting phenolic compounds and flavonoids, both at the site of infection and in other parts of the plant. The production and transport of these compounds is controlled in large part by the nutrition of the plant. Therefore, shortages of key nutrients such as K, Mn, Cu, Zn, and B reduce the amount of the plants natural antifungal compounds at the site of infection.

It has been demonstrated that when B is deficient, plant cell walls tend to swell and split, and to result in weakened intercellular space. This results in a weakened physical barrier to initial infection and expansion of the infection. Boron also plays a role in the production of disease protection compounds and structures within plants. With a shortage B, the plant exudates contain higher amounts of compounds such as sugars and amino acids that promote the establishment of most fungal infections.

Boron has been beneficial in the control of the following diseases. This list is not necessarily all-inclusive and some pathogens may affect more plant species than those listed.

CROP	COMMON NAME OF DISEASE	SCIENTIFIC NAME OF DISEASE
Various crucifers	Club root	Plasmodiophora brassicae
Beans	Root rot	Fusarium solani
Various	Yellows	Fusarium oxysporum
Tomato	Wilt	Verticillium albo-atrum
Cotton	Wilt	Verticillium albo-atrum
Mungbean	Stem rot	Rhizoctonia solani
Peanut	Charcoal rot	Rhizoctonia bataticola
Beans	Tobacco mosaic virus	Tobacco mosaic virus
Tomato	Yellow leaf curl virus	Yellow leaf curl virus
Potato	Potato wart disease	Synchytrium endobioticum
Wheat	Mites	Petrobia latens

Copper (Cu)

The usefulness of Cu for disease prevention and correction was well known by 1900. This was about 30 years before it was determined to be an essential nutrient. Actually, the work with the fungicidal properties of copper led to the discovery that it is an essential nutrient as well. Like Mn, copper is an essential nutrient for higher plants as well as fungi and bacteria. Copper is also very toxic to all plant forms when present at high levels. However, higher plant forms such as crops and ornamentals can tolerate much higher Cu levels than lower forms, such as fungi and bacteria. This difference in tolerance enables growers to use Cu as a disease treatment. Copper fertilization has decreased the severity of a wide range of fungal and bacterial diseases. While Cu is known to control diseases when foliar applied, many times foliar diseases were controlled with soil applications of Cu.

When a plant becomes infected by a fungus, its natural defenses are triggered. The infection causes increased production of fungus inhibiting phenolic compounds and flavonoids, both at the site of infection and in other parts of the plant. The production and transport of these compounds is controlled in large part by the nutrition of the plant. Therefore, shortages of key nutrients such as K, Mn, Cu, Zn, and B reduce the amount of the plants natural antifungal compounds at the site of infection.

Another plant response to infection is the formation of oxygen radicals ($O^{=}$ and OH^{-}) and hydrogen peroxide (H_2O_2). These elements and compounds can be destructive to the plants cells as well as the pathogen. It is also thought that in some cases there may be over-production of both agents. In either event, Cu acts to detoxify oxygen radicals and hydrogen peroxide, thus limiting damage to plant cells.

Copper has been beneficial in the control of the following diseases. This list is not necessarily all-inclusive and some pathogens may affect more plant species than those listed.

CROP	COMMON NAME OF DISEASE	SCIENTIFIC NAME OF DISEASE
Wheat	**Mildew**	**Blumaria grammis var. tritici**
Sunflower	**Leaf/Stem spot**	**Alternaria**
Ginseng	**Bacterial leaf spot**	**Pseudomonas cichorii**
Wheat	**Leaf rust**	**Puccinia triticina**
Rye	**Ergot**	**Claviceps purpurea**
Barley	**Ergot**	**Claviceps purpurea**
Rice	**Blast**	**Pyricularia oryzae**
Wheat	**Leaf/Glume blotch**	**Septoria**
Sugarbeet	**Nematode**	**Heterodera**
Tomato	**Wilt**	**Verticillium albo-atrum**
Cotton	**Wilt**	**Verticillium dagliae**
Potato	**Common scab**	**Streptomyces scabies**
Eucalyptus marginata	**Root rot**	**Phytophthora cinnamomi**
Wheat	**Take-all**	**Baeumannomyces graminis var. tritici**

Research into the fungicidal properties of Cu has been conducted using foliar applications that are 10 to 100 times as high as those recommended for foliar fertilization. However, it has been demonstrated that plants which have low tissue levels of Cu (by nutrient standards) are more susceptible to various diseases. Therefore, the disease suppression capabilities of Cu can be said to occur over a wide range of concentration, and to function both as a direct inhibitor to various diseases as well as enabling plants to better defend themselves from disease.

The micronutrients Cu, Mn, Zn, and Fe are divalent cations in their soluble, plant available forms and they are antagonistic toward each other. This antagonism is seen occasionally in nutrient uptake, but it is also reported in relation to disease control. An experiment with tomatoes by Tomono, et al, in 1982 found that Zn^{++} essentially negated the fungicidal effects of Cu treatments. As will be discussed later, Zn also has fungicidal properties. However, Zn is much less toxic to many pathogens than is Cu. When uptake of Cu was suppressed by excess Zn, the stronger disease control benefits of Cu were also reduced. Thus, there was a net increase of disease in the plants.

Manganese (Mn)

Manganese has long been known to contribute to the suppression of fungus and bacterial diseases, and has been one of the active ingredients of some fungicides. Manganese plays a key role in the production of phenolic compounds and lignin formation, two of the major items in a plants arsenal against disease. When a plant becomes infected by a fungus, its natural defenses are triggered. The infection causes increased production of fungus inhibiting phenolic compounds and flavonoids, both at the site of infection and in other parts of the plant. The production and transport of these compounds is controlled in large part by the nutrition of the plant. Therefore, shortages of key nutrients such as K, Mn, Cu, Zn, and B reduce the amount of the plants natural antifungal compounds at the site of infection. Phenolic compounds are toxic to many disease pathogens and lignin is a physical barrier to penetration by disease organisms.

Plants also respond to fungal infection by forming oxygen radicals ($O^{=}$ and OH^{-}) and hydrogen peroxide (H_2O_2), both of which help to fight infections. Both are damaging to disease organisms. However, they are also damaging to the tissue of the host plant and must be detoxified at some point. Manganese plays a role their formation and later de-toxification. While, excess Mn can be toxic to higher plants, they require much more Mn that fungi and bacteria. It may be the case that by supplying high levels of Mn to some plants through fungicides or nutrition, we are causing a simple Mn toxicity for fungi and bacteria.

The incidence of infection of potato tubers by *Streptomyces scabies*, leading to common scab, is reduced by either lowering the soil pH (which increases the amount of soluble Mn) or by applying large amounts of Mn to the soil. The mode of action in suppressing *S. scabies* is by directly inhibiting the vegetative growth of the fungus.

In Norway spruce, the inner bark of roots is less capable of fungistatic activity against the pathogen *Fomes annosus* than is the outer bark. When this disease is established, it leads to heart root disease by affecting this weaker area of the roots. When these trees are supplied with high Mn and low N, the fungistatic capability of the inner bark increases.

It is commonly found that diseased plants have much lower Mn content than healthy plants. While there can be many reasons for this, it illustrates the intimate relationship between Mn and plant diseases. Some soil-borne fungi have the ability to oxidize soil Mn, making it unavailable to higher plants. This can lead to reduced Mn uptake and lower disease resistance in the crop or target plant. Additionally, some diseases damage roots or the vascular system (xylem) of plants, thus lowering the Mn and other nutrient content of the leaves and stems, with the result that the plant becomes more susceptible to the disease. As the nutrient levels of the above-ground tissue decrease, the disease progresses faster and other problems can occur.

Manganese plays a role in the ability of wheat and barley to resist “take-all” (*Gaeumannomyces graminis*). This disease thrives in a neutral or alkaline soil pH, and is very sensitive to acid soil. Manganese availability in the area of the roots and the Mn content of the roots has a direct effect on the severity of take-all. As the soil pH increases, the availability and uptake of Mn decreases significantly. This fungus also has the capability to oxidize soil Mn, making it unavailable. The resulting drop in Mn uptake by the crop reduces its ability to synthesize lignin, which reduces its ability to resist infection. Foliar sprays of Mn are not very effective in fighting take-all due to the limited mobility of Mn from the leaves to the roots. Soil applications of Mn on high pH soils are also not very effective due to the rapid oxidation and immobilization of Mn when applied to these soils.

Manganese has been beneficial in the control of the following diseases. This list is not necessarily all-inclusive and some pathogens may affect more plant species than those listed.

CROP	COMMON NAME OF DISEASE	SCIENTIFIC NAME OF DISEASE
Potato	Common scab	Streptomyces scabies
Rice	Blast	Pyricularia oryzae
Rice	Leaf spot	Alternaria
Wheat	Mildew	Blumaria grammis var. tritici
Cotton	Wilt	Verticillium alboatrum
Avocado	Root rot	Pythium
Norway spruce	Annosum root rot	Fomes annosus
Swede	Powdery mildew	Erysiphe polygoni

Zinc (Zn)

Work as early as the 1920's show that plants deficient in Zn were more subject to various diseases. Reports at the time indicated that Zn improves a plants ability to defend itself from diseases. Today, information on the specific relationship of Zn to plant pathogens is somewhat mixed. Some sources suggest that there is no clear evidence to explain how Zn suppresses some diseases, while others indicate that Zn is directly toxic to many disease organisms. The fact that Zn is an active ingredient in some fungicides is evidence that it is directly toxic to some pathogens. Evidence also indicates that soils low in soluble Zn (available to higher plants) are more likely to support higher populations of some disease causing organisms. However, some species of Fusarium (F. oxysporum and F. lycopersici) have a higher demand for Zn than many crop species, and exhibit less growth and virulence when deprived of Zn in isolated cultures. In other work, Zn has reduced the effects of some Fusarium species.

When a plant becomes infected by a fungus, its natural defenses are triggered. The infection causes increased production of fungus inhibiting phenolic compounds and flavonoids, both at the site of infection and in other parts of the plant. The production and transport of these compounds is controlled in large part by the nutrition of the plant. Therefore, shortages of key nutrients such as K, Mn, Cu, Zn, and B reduce the amount of the plants natural antifungal compounds at the site of infection.

Another response to infection is the formation of oxygen radicals ($O^{=}$ and OH^{-}) and hydrogen peroxide (H_2O_2). These elements and compounds can be destructive to the plants cells as well as the pathogen. It also thought that in some cases there may be over-production of these materials. In either event, Zn aids both in the production and detoxification of oxygen radicals and hydrogen peroxide, thus limiting damage to plant cells.

Zinc is essential to the integrity and stability of plant membranes and it is thought to help prevent "leakage" of essential elements or compounds from plant cells. It is known that Zinc shortages contribute to the accumulation of unused sugars within the plant. It has been found in some plants that a Zn deficiency caused the leakage of sugars onto the surface of the leaf. This excess sugar, plus some leakage of sugar onto the plant surfaces, can enhance the successful invasion of fungus and bacteria. In summary, it can safely be concluded that improving the Zn nutrition of crops will be helpful against many, but not all diseases.

Feeding intensity and reproduction by sucking insects tend to be higher on plants with a higher amino acid content. This condition is typical of plants with a Zn deficiency, or a relative excess of N compared to these nutrients. While the direct damage from these insects is important, they may also be a vector for viruses.

Zinc has been beneficial in the control of the following diseases. This list is not necessarily all-inclusive and some pathogens may affect more plant species than those listed.

CROP	COMMON NAME OF DISEASE	SCIENTIFIC NAME OF DISEASE
Various	Root rot	Phytophthora megasperma
Various	Root rot	Phytophthora dreschsleri
Oranges	Root rot	Phytophthora nicotiana
Citrus	Mold	Penicillium citrinum
Various	Leaf spot	Cochliobolus miyabeanus
Cranberries, others	Leaf spot	Cladosporium cladosporoides
Various trees	Decay, vascular	Trametes versicolor
Various trees	Wood rot	Stereum strigosazonatum
Various	Rot	Trichoderma
Various	Leaf spot	Alternaria
Various	Leaf spot	Epicoccum
Various	Wilt	Fusarium
Various	Stem/sheath blight	Rhizoctonia solani
Cotton	Wilt	Verticillium
Tomato	Nematode	Rotylenchulus reniformis
Cotton	Root rot	Phymatrotrichopsis omnivorum
Ginseng	Bacterial leaf spot	Pseudomonas cichorii
Chickpea	Root rot	Fusarium
Peanut	Rot	Rhizoctonia bataticola
Rubber trees	Powdery mildew	Oidium heveae
Wheat	Take-all	Gaeumannomyces graminis var. tritici
Wheat	Head scab	Fusarium graminearum
Watercress	Crook root	Spongospora subterranea
Watercress	Leaf spot virus	Spongospora subterranea (vector)
White clover	Clover phyllody	Phyllody virus
Eucalyptus	Crown/root rot	Phytophthora cinnamomi
Soybean	Foot rot	Sclerotium rolfsii
Pea	Powdery mildew	Erysiphe polygoni

Iron (Fe)

While there is some evidence that Fe is active against some diseases, it is not considered in the same category as K, Mn, Cu, or Zn. Evidence suggests that plant pathogens generally have a high requirement for Fe. Some work suggests that the competition for Fe between higher plants and pathogens is a factor in the infection of higher plants. It is not clear if plants use the competition for Fe as a defense mechanism against disease.

When a plant becomes infected by a fungus, its natural defenses are triggered. The infection causes increased production of fungus inhibiting phenolic compounds and flavonoids, both at the site of infection and in other parts of the plant. The production and transport of these compounds is controlled in large part by the nutrition of the plant. Therefore, shortages of key nutrients such as K, Mn, Cu, Zn, and B reduce the amount of the plants natural antifungal compounds at the site of infection.

Another response to infection is the formation of oxygen radicals ($O^{=}$ and OH^{-}) and hydrogen peroxide (H_2O_2). These elements and compounds can be destructive to the plants cells as well as the pathogen. It also thought that in some cases there may be over-production of these materials. In either event Fe has a role in both the production and detoxification of oxygen radicals and hydrogen peroxide, thus limiting damage to plant cells.

Some work has shown that increased Fe availability or uptake can actually increase disease severity. For example, tomato tolerance of Fusarium wilt was decreased by Fe without affecting the development of the fungus. In this case, Fe also stimulated fungal spore germination. In other work, supplemental Fe increased the disease incidence and severity of Take-all in wheat and barley. In the table below, note that where take-all fungus was present in a soil that normally suppresses this fungus and Fe was applied, the fungus became nearly as damaging as in the control sample of the conductive soil. Thus, the application of Fe essentially negated the suppressive effects of the soil.

EFFECT OF Fe ON THE SURVIVAL OF BARLEY SEEDLINGS AS AFFECTED BY "TAKE-ALL" FUNGUS

	SEEDLING SURVIVAL (%)	
TREATMENT	**SUPPRESIVE* SOIL**	**CONDUCTIVE* SOIL**
Control	83	27
FeEDTA (50 µM)	38	25
FeEDTA (no take-all fungus)	85	87

From Kloepper et al., 1980

*The soil feature that made it suppressive or conductive to take-all fungus was not specified, but we assume that it was soil pH. Acid soil suppresses take-all fungus.

In plant nutrition and soil chemistry, the micronutrients Mn, Cu, Fe, and Zn are antagonistic to each other. Additionally, many plants are somewhat sensitive to the Fe:Mn ratio in the tissue. Since we know that Mn, Cu, and Zn have significant anti-disease properties or actions, it seems possible that surplus Fe may simply be depressing the activity of one of these other elements. Iron has been beneficial in the control of the following diseases. In most cases, the beneficial effects required foliar Fe applications, some at high concentrations. This list is not necessarily all-inclusive and some pathogens may affect more plant species than those listed.

CROP	COMMON NAME OF DISEASE	SCIENTIFIC NAME OF DISEASE
Wheat	Rust	Puccinia recondita
Wheat	Smut	Tilletia sp.
Banana	Anthracnose	Coletotrichum musae
Apple	Black rot	Sphaeropsis malorum
Pear	Black rot	Sphaeropsis malorum
Cabbage	Virus vector	Olpidium brassicae

Chlorine (Cl)

The element chlorine, when present as the chloride ion (Cl^-) is considered to be an essential micronutrient for nutritional purposes. It also has significant disease control benefits when applied at rates similar to those of major or secondary nutrients. There is no agreement on the exact mechanism by which Cl acts against disease. In excessive amounts, Cl is also a factor in salinity stress or plant damage. Thus, the effects of Cl range from those of a micronutrient in low amounts, through a disease preventative in intermediate amounts, to a toxin in excessive amounts.

While there are many examples of Cl fertilization being beneficial to crops, some crops can be damaged by Cl levels that are beneficial to others. It has been know for many years that tobacco and blueberries are adversely affected by relatively low levels of Cl. Some varieties of soybeans grown in the Southern U.S. such as Bragg, Braxton, Cobb, Foster, and GaSoy 17 are also susceptible to damage by Cl. Other crops reported to have some sensitivity to high Cl levels are alfalfa, potatoes, cotton, tomatoes, and grain sorghum. Some of these same crops have also been shown to benefit from moderate Cl application. As is often the case, the benefit or danger lies in the rate of application.

Chlorine has been beneficial in the control of the following diseases. In most cases, the beneficial effects required Cl applications in excess of the plants nutrient needs, but less than that expected to cause salinity problems. This list is not necessarily all-inclusive and some pathogens may affect more plant species than those listed.

CROP	COMMON NAME OF DISEASE	SCIENTIFIC NAME OF DISEASE
Corn	Stalk rot	Gibberella zeae
Corn	Stalk rot	Gobbler Fujikuroi
Corn	Stalk rot	Fusarium moniliforme
Corn	N. Corn leaf blight	Exserohilum/Helminthosporium
Soybean	Sudden death syndrome	Fusarium solani
Wheat	Stripe rust	Puccinia striiformis
Wheat	Leaf rust	Puccinia recondita
Wheat	Take-all	Gaeumannomyces graminis var. tritici
Wheat	Leaf/Glume blotch	Septoria nodorum
Wheat	Tan spot	Pyrenophora tritici-repentis
Wheat/Barley	Root rot	Cochliobolus sativus
Millet	Downey mildew	Pennisetum typhoides
Potato	Hollow heart	Physiological disorder, not disease
Potato	Brown center	Physiological disorder, not disease
Turf	Necrotic ring spot	Leptosphaeria korrae
Palm tree	Leaf spot	Pestalozzia palmarum
Celery	Fusarium yellows	Fusarium

Silicon (Si)

While Si is not included in the list of essential elements or nutrients, it can be beneficial in reducing disease in some plants. Evidence indicates that one of the mechanisms by which Si protects plants is by increasing the effectiveness of the mechanical barrier that plants present to infection. Increased Si in plants has been shown to increase the difficulty of sucking insects, like aphids or leaf hoppers. Decreased feeding by these insects could also aid in the prevention of the spread of viral diseases that could be transmitted by the insects.

Additional information indicates that Si may play a more active role in fighting disease. Some work has found that there was a higher amount of Si around unsuccessful infection sites in plants, than in successful infections. This appears to indicate that the increased amount of Si was a factor in suppressing the infection, and that it was transported to the site of infection. Some work has found a correlation between the accumulation of phenolic compounds around infection sites and the accumulation of Si around the same sites. It is postulated that Si may play a role in the transportation of the disease fighting phenolic compounds to the infection sites.

Silicon has been beneficial in the control of the following diseases. This list is not necessarily all-inclusive and some pathogens may affect more plant species than those listed.

CROP	COMMON NAME OF DISEASE	SCIENTIFIC NAME OF DISEASE
Rice	Rice blast	Piricularia oryzae
Rice	Brown spot	Cochliobolus miyabeanus
Barley	Powdery mildew	Erysiphe graminis
Cucumber	Powdery mildew	Sphaerotheca fuliginea
Grapes	Powdery mildew	Uncinula necator
Beans	Rust	Uromyces phaseoli
Various	Rust	Various

Molybdenum (Mo)

Little is known about the effects that Mo may have on plant diseases. It has been reported that Mo applied to tomato roots reduced the symptoms of Verticillium wilt and that Mo reduced the production of a toxin by Myrothecium roridum, a pathogen of muskmelon. A report indicated that Mo “slightly” decreased the reproduction of Phytophthora cinnamomi and Phytophthora dreschleri diseases of a variety of crops. A report indicated that soil applications of Mo decreased the populations of the nematode Rotylenchulus reniformis, which infects various crops.

It is not known whether Mo within a plant plays any role in protection against diseases. It is possible that any effect of Mo deficiency on plant diseases may be indirect, through its role in N metabolism.

Nickel (Ni)

Nickel is sometimes listed with the essential elements, or as a potentially essential element. It is also listed as a heavy metal, and as such its application to land is regulated. Nickel plays a key role in N metabolism in plants. However, since the critical level in plants is reported to be between 10 and 100 ppb (parts per *billion*), it is unlikely that growers will find a need to include it in fertilizers any time soon.

A 1985 study showed that the number of rust pustules on infected cowpeas was reduced more than 50% by increasing the supply of Ni to the roots from 30 ppb to 3.3 ppm. The resulting leaf concentration of only 1 ppm was effective in reducing the level of rust infection. Ni has also been found to be effective in protecting rice against rice blast fungus (Pyricularia oryzae) and brown spot (Cochliobolus miyabeanus)

Cadmium (Cd)

Cadmium is not considered to be an essential element, and can be toxic to plants in low quantities. As little as 3 ppm in nutrient solutions will depress the growth of most plants. Like Ni, it is also a heavy metal and Cd application to land is regulated. Cadmium at low concentrations has been found to stimulate or enhance the formation of lignin in wheat, which is known to be a disease defense mechanism, and to suppress the effects of powdery mildews in a variety of crops.

Lithium (Li)

Lithium is not considered to be an essential element, and can be toxic at low levels. Lithium was found to be toxic to citrus at soil levels in excess of 2 to 5 ppm. Like Cd, Li has been shown to significantly suppress the effects of powdery mildews.

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