Nutritional & Microbial Methods of Suppressing Plant Diseases & Pests

Plants have many ways to protect themselves from disease and insect attack.
Technically, plants resist pest attacks by two GENERAL methods:

1) Resistance – Physical Barrier, Chemical Response & Biological Management.
2) Tolerance – Healthy plants (roots) "outgrow" disease.

Resistance is obtained by changes in the plants physical characteristics like thicker epidermal cells, higher degree of lignification and/or silification (silica). Plants can obtain more resistance also by developing an increased ability to produce inhibitory or repelling substances.

In other words, resistance in pest attacks results from increasing the mechanical barrier (physical) and producing toxins (chemical - phytoalexins). These tools are especially efficient when they can be used in timing with the highest incidence of the disease or the plants most susceptible time to disease attack (young growth).

An entire new topic is the management of root and leaf microbiology. This exciting new field "manages" microbiology so that "good" microbes outgrow "bad" microbes (biological).

Tolerance is when a plant is simply able to outgrow the attack from an insect or plant disease. This occurs in plants that could loose leaves due to disease, or roots, but still produce a good yield.

A good way to visualize the natural ability of plants to suppress disease is to visit a variety plot of a crop such as tomatoes or potatoes. Many times the objective of the plot is to determine which varieties are disease/insect resistant, so chemical controls are not likely utilized. You will immediately notice that some plants will be totally destroyed by an insect or disease, while the one right next to it is perfectly healthy.

The question is, WHY? Or better yet, how can we apply this to agriculture?

WARNING -- As a rule, using nutritional approaches for plant disease suppression is most effective in plants (and varieties) that have some natural suppression. Nutrition can effectively increase this suppression. However, plants that a naturally weak and susceptible to a particular pest problem cannot simply be "fed" out of intolerance. The more natural genetic ability that is present, the more likely nutritional balance will help. A method of knowing this is to observe whether, or not, a crop is capable of disease resistance in some parts of a field (or fields), and then studying which nutrients would be higher (or lower) in these plants verses those that get diseased.

To avoid repetition on mechanisms of disease suppression we will first generally define how the disease/pest problems affect the plant and then introduce each nutrient and nutrient mechanism by which the plant will show improved natural resistance.

Common Plant Diseases

Fungal Diseases

Most parasitic fungi (parasitic = cause damage) like powdery mildew can only invade roots and leaf surfaces by the presence of plant exudates. Plant exudes are simply compounds that the plant makes as it grows and used for it basic functions. The primary compounds that support parasitic fungi are amino acids (low molecular weight or small proteins) and simple sugars. In most cases the problem is that there is:

1) An excess of these compounds.
2) A poor conversion of simple to complex compounds (amino acids to protein or sugars to starch).
3) That cells are incapable of "holding" these compounds in and the leak out.

It is important to note that there are two groups of fungi that are problems and that they attack with different mechanisms.

The first group is *obligate* parasites. In biology the word obligate refers to the fact that it can only survive on a particular condition or purpose. Obligate parasites are those that require the "food" described above, amino acids and sugars. Examples of obligate parasites are rust diseases and powdery mildew.

The second group is *facultative* parasites. These are the opposite of obligate, in that they are capable of surviving under different conditions and can have varying purposes. Facultative parasites damage plants by attacking senescing (weak and dying) tissue or by producing toxins that damage and kill cells. Examples of facultative parasites are leaf spot diseases, wilt and rot disease and bacterial spots or wilt.

Bacterial Diseases

Bacterial diseases are caused by facultative parasites that cause leaf spot diseases (leaf blight), soft rot and vascular diseases. The important difference to remember is that bacterial parasites are small compared to fungi and some have the ability to enter the plant through the stomata, therefore the cuticle wax and upper layer of cells (epidermal cells) do not have a positive effect on blocking out the disease causing organisms.

Bacterial vascular disease spreads through the plant by moving in the xylem; therefore they are very mobile and capable of "plugging" this important pipeline causing many more problems.

Viral Diseases

The multiplication of viral diseases is confined to living cells and their nutritional requirements are restricted to amino acids and nucleotides (basic part of RNA and DNA). Very little data is found how mechanisms of nutritional suppression, but one important point must be considered, that a virus needs to be "vectored" (carried in) by another organism, mainly an insects (aphids) or fungi. Therefore, suppression of the vectors will lessen the effect of viruses.

Soilborne Fungal & Bacterial Diseases

The population density of microorganisms at the root surface is many times higher than in the surrounding soil. Under cool, wet or anaerobic conditions it is often possible that the development of negative parasites can develop. We must state "negative" because technically a very beneficial group of fungi (mycorrhizae) actually "invade" the root hair also.

Soilborne diseases are a result of more factors than only improper plant nutrition; however, important plant nutrients like calcium also play an important role in the structure (porosity) of soils. Low calcium soils do not have proper aggregate structure, therefore and generally more anaerobic and more contusive to harboring anaerobic disease causing organisms.

Soilborne diseases are actually any entirely different topic of soil microbiology and microbial balance, but plant nutrition also affects the nutritional status of roots and therefore plant nutrients can affect the ability of roots to suppress disease.

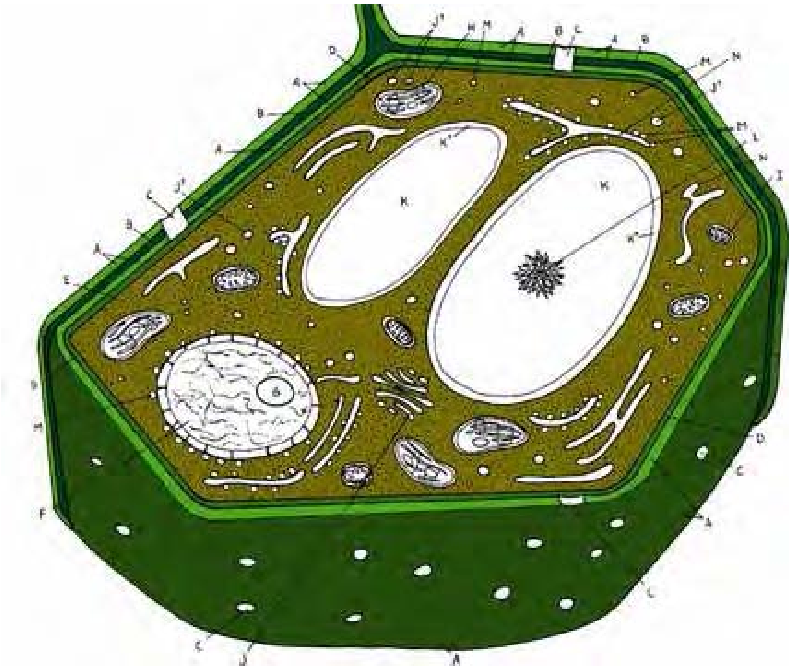
Plant Pests

These are "animals" such as insects, mites and nematodes. They can be directly harmful to plants by eating them and indirectly harmful by weakening plants and causing excess disease pressure or a "vector" point or opening.

One problem with these pests is that their "dietary" requirements are not very specific. However, there are some interesting and nutritionally controllable factors that need to be addressed.

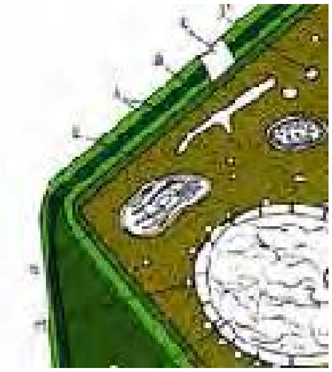
Before one can full appreciate the mechanisms by which a plant can protect itself from disease and insect attack, one must take a closer look at the cell itself and the components that are important in this factor.

The Cell – In Relation to Disease



The parts of the cell that we are primarily concerned with in relation to plant disease are the four outer layers:

A. The cell wall
B. Middle lamella
C. Plasmodesmata
D. Plasma membrane

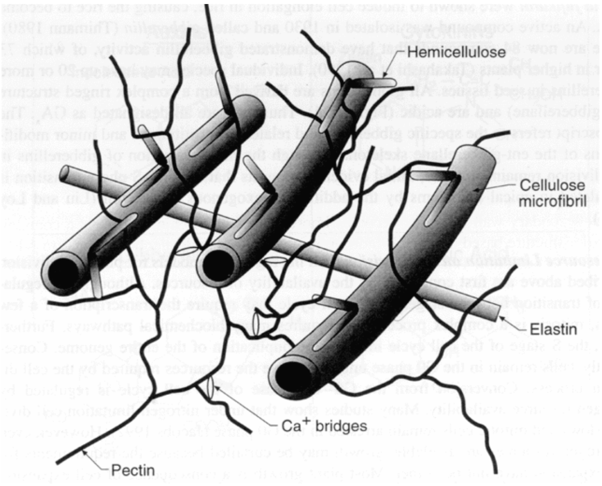


A. The cell wall is the combination of the 1st three layers; two "mats of fiber" which are "glued" together by a "polymerized gel".

B. Middle lamella – The "polymerized gel" is like glue that binds the two layers together and forms the cell wall.

C. Plasmodesmata – important in the translocation of nutrients and cell material, but not directly involved in the structure of the cells ability to suppress disease.

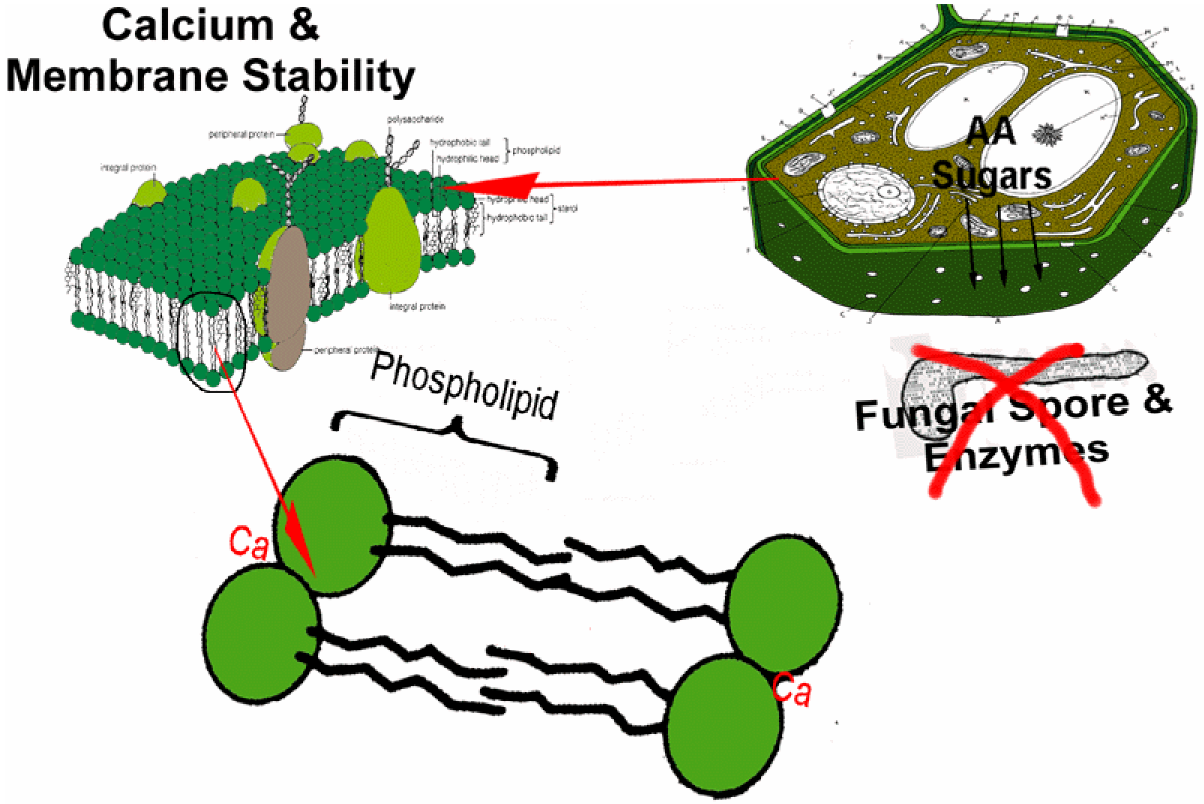
D. Plasma membrane – The 2nd "line of defense" which keeps the disease "food" (simple amino acids & sugars) in the cell. This is also a very important part of natural disease suppression.



One unique feature of plant cells is the cell wall, a porous, nonliving, supportive, and protective shell. The cell wall is constructed by the protoplast, the living part of the cell. In multicellular plants, cell walls of adjacent cells are in contact and held together by the middle lamella, a thin cementing layer.

This structure can be likened to two layers of fiberglass glued together by the middle lamella. Boron (B) plays a role in the polymerization of the glue (pectin). The more complex the polymers (the thicker the glue) the better it can bind the layers of fiberglass. Calcium (Ca) plays an important role in "hardening" (calcium bridges) the glue. Together (2 layers of fiberglass + glue (B)) this makes up (A) the cell wall.

A single membrane closely appressed to the cell wall is the important plasma membrane (D) the "filter". Unlike the cell wall, the plasma membrane is not freely porous to substances. Instead, it mediates the movement of substances into and out of the protoplast by selective control. This "filter" is held together by calcium, the lower the calcium, the more "holes" the filter has which results in cell "leakage" which is food for disease.



The Cell – A Physical Barrier

The purpose of illustrating the basic structure of the cell is to identify how a disease organism attacks a plant and how it gets "food" to reproduce and grow. This leads to the next logical step, which is how this natural "defense" mechanism can be utilized to make plants healthier and more resistant to disease by acting as a physical barrier and keep disease food away from the disease organism.

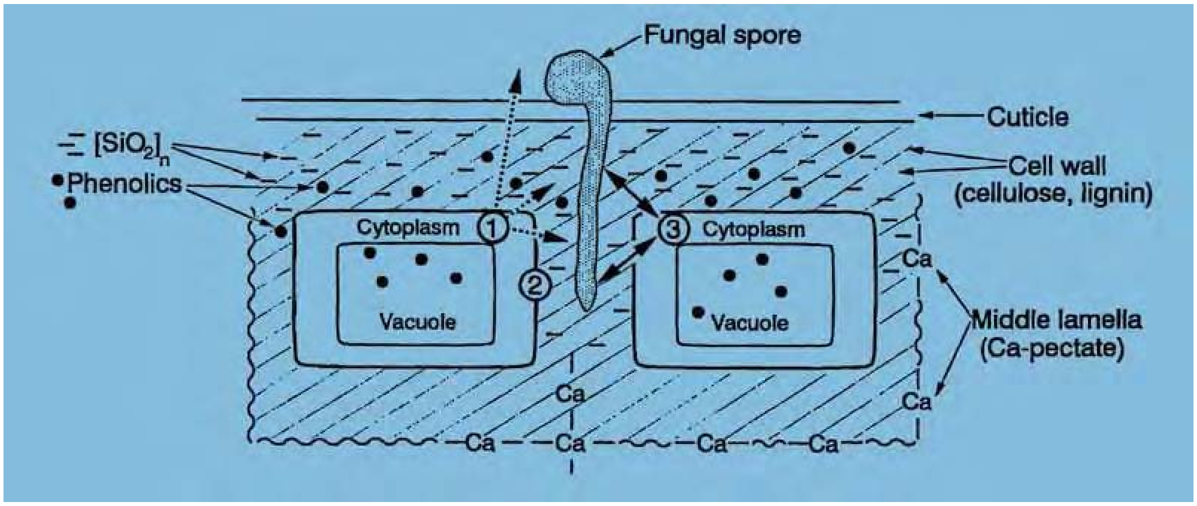
Disease "food" – Amino Acids & Sugars

Leaves, made of cells, then have various mechanisms of keeping out disease. Generally;

1. Physical Barrier #1 - Waxy Layer on the leaf (keeps the disease organism from penetrating).
2. Physical Barrier #2 - The cell wall (keeps the disease organism from penetrating & keeps "food" away).
3. Physical Barrier #3 – The plasma membrane prevents disease "food" from leaking out (keeps "food" away).

This introduces a major mechanism of disease suppression. Further mechanisms will be discussed after the section following which is about each major disease suppressing nutrient and its function.

Taking a closer look at this cell wall with a fungal spore invading, it would look a lot like this:



Building a Defense

One Nutrient at a time

The cuticle is the first barrier against a fungal spore. Because most airborne spores have only a limited amount of "energy" to penetrate (drill into) the cell wall, the thicker this waxy layer is, the more unlikely a spore can penetrate and get nutrient to survive. Healthy plants have good waxy leaves and weak plants have thinner leaves. In this function, plant disease (powdery mildew) is actually a mechanism by which nature eliminates the weak and preserves the strong.

This is why in tropical areas; all the plants have a thick, hard leaf, which cannot be easily penetrated.

Once the spore gets through the cuticle layer, it must deal with the cell wall, itself. Take particular notice of the contents of a cell wall, the cellulose, lignin, phenolics and silica compounds.

Silica

Silica is one of the two "systems" a plant can use to protect itself. The reason one can say "one of two" is that certain plant species, especially grasses (wheat, rice etc.) have naturally higher levels of silica than plants with the next two types of nutrients we will cover, calcium and boron. The calcium and boron system is not separate from silica, only that plants which require large amounts of calcium (apples, tomatoes, potatoes) do not contain a lot of silica.

This does not necessarily eliminate the use of silica in plants that do not require it, but it does illustrate the need to test this method and gauge its feasibility by field trials.

Silica works by forming a physical barrier in the epidermal cells against the penetration of fungal hyphae, or insects such as aphids. Silica not only acts as a physical barrier, but that in a soluble form it is thought that it aids in the translocation of phenolic compounds to the cell wall. A copper-containing enzyme that will be explained in more detail latter is very important in the production of these phenolic compounds. Silica can be made available as much as required, but if this copper enzyme is low, phenolic compound production is low and therefore this mechanism is made less effective. (Balance, balance, balance)

There is evidence that silica can concentrate at points of disease entry. For example, in wheat tissue work, it has been demonstrated that 3 to 4 times the silica is present at the points of the leaf surface that mildew spores attack, verses levels where there is no mildew.

Research has also demonstrated that additions of silica to naturally low silica-containing plants such as grapes and cucumbers can also have a very positive effect on disease suppression.

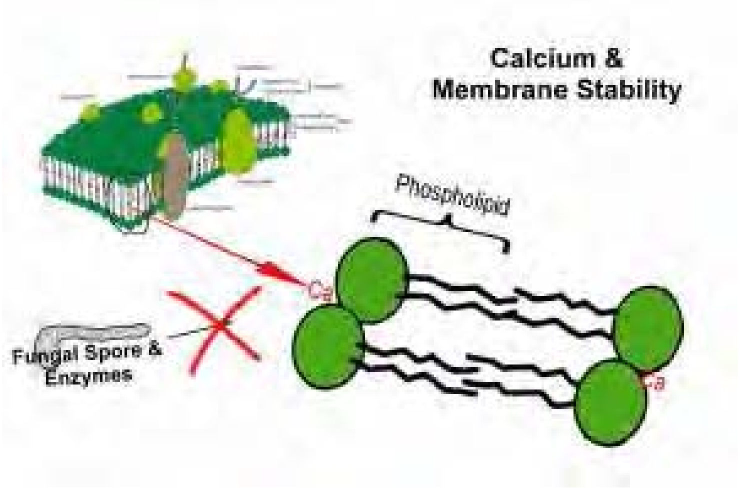
Silica does have its limitations, in that it is preferentially transferred in the xylem to mature leafs. Most disease attacks young growth because of an excess of low molecular weight compounds in the plant, lack of lignin formation and other factors. Also that once silica polymerizes it forms unexhangable compounds and cannot be retranslocated.

Calcium

Calcium protects plants in three important ways:

1) Calcium is essential for the stability of biomembranes (Plasma membrane), when calcium is low; the low molecular weight compounds that "feed" disease (amino acids and sugars) are easily moved into the apoplasm (outside).
2) Calcium polygalacturonates are required in the middle lamella for cell wall stability. Many parasitic fungi and bacteria invade plant tissue by producing an enzyme that dissolves this layer. The activity of this enzyme is drastically reduced by calcium.
3) "Hypersensitive" response to disease (SAR or ISR)

Most of the calcium found in plants is found in the cell wall. For example, in apples, up to 90% of the calcium is found bound to the polygalacturonic acids (pectin)
By knowing which type of fungi is obligate and which is facultative, one can figure out which of the above 2 mechanisms is most effective in the control of a particular disease. Powdery mildew, being obligate, will best be suppressed by a strong, mature cell wall which will act as a physical barrier and not allow the spore to "drill" into the cell for food.



On the other hand, various facultative parasitic fungi, such as fusarium wilt, invade the xylem and dissolve the cell walls of these nutrient pipelines. Studies have proven that by maintaining a high level of calcium in the plant, this disease cannot function.

Bacterial diseases such as bacterial leaf blight are capable of directly entering the plant through the stomata, therefore by passing the cuticle layer and the epidermal cells. However, bacterial disease infects the plant by producing polygalacturonases and related pectolytic enzymes. Calcium is most effective at reducing the activity of these enzymes.

Calcium can also suppress bacterial infections in another method. This is a hypersensitive response to bacterial invasion, were the plant sends huge amounts of calcium from the apoplasm into the cytoplasm leading to enhanced K and H exchange with acidifies the cytoplasm causing death of the host cells at infection sites. Basically, the plant "sacrifices" a part of itself to keep the disease from spreading. This mode of action can also happen with various fungal parasites also.
It should be particularly noted that high levels of calcium are even more important when using higher rates of potassium fertilizers, especially when in conjunction with higher rates of N.

Although K is essential for disease suppression, high levels will cause a higher rate of movement of amino acids and sugars into the apoplasm, if calcium is not present in sufficient quantities. Consider the following data in observing the K : Ca ratio in lettuce infected with *Botrytis*.

Relationship Between Cation Content and Severity of Infection with *Botrytis cineria* Pars. In Lettuce

Cation Content in mg/g			Infection with Botrytis
K	**Ca**	**Mg**	***
14.4	10.6	3.2	4
23.8	5.4	4.1	7
34.2	2.2	4.7	13
48.9	1.8	4.2	15

*** Infection Index: 0-5 = slight infection, 6-10 = moderate & 11-15 = severe

Calcium is very important in a plant's ability to naturally suppress disease, however, as with most plant functions, these calcium mechanisms must also be supported. Boron plays and important role in this process.

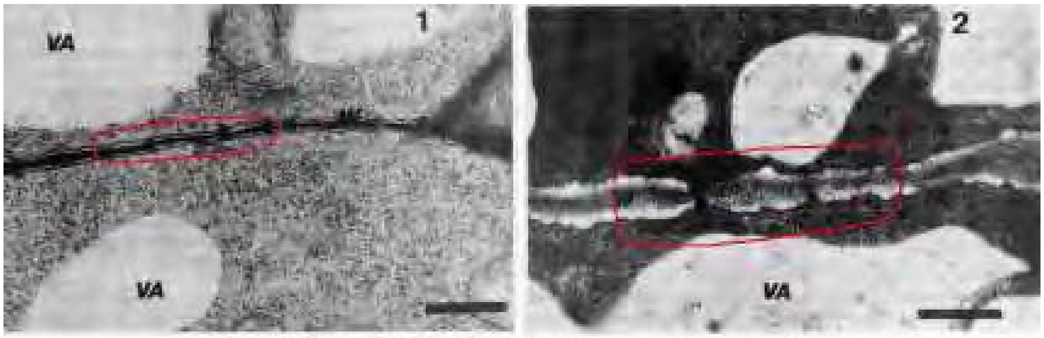
Boron

In relation to plant disease, boron plays an important role in the polymerization (joining simple molecules into more complex ones) of galactomannans and other pectic substances. This means that the production of this important calcium protected defense layer is produced by the presence of boron.

Although the mode of action is not clear, boron also could play a role in the production of phenolic compounds used in the production of lignin. Phenol production is very light sensitive (the more light the more production), however, with adequate levels of boron, this production is even more effective even at lower light conditions (cloudy days).

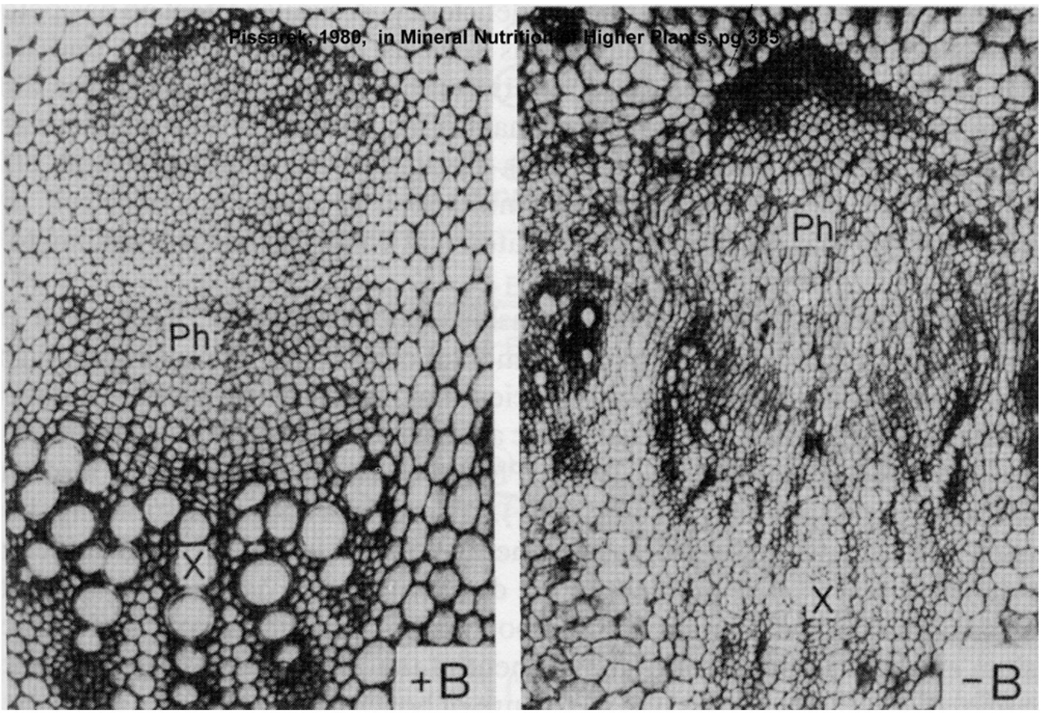
The level of boron in plants is determined by its method of disease suppression. It has already been stated the grass species (wheat, etc) contain higher levels of silica, whereas dicots contain higher levels of calcium. This corresponds with boron levels also. Most grasses require from 5 to 10 ppm of boron, while dicots require from 20 to 70 ppm.

Boron is very important in the proper development of cell walls and the nutrient pipelines. In severely deficient plants the cell wall does not form properly as illustrated below. Notice that a deficient cell wall appears thicker, but this is an indicator of the imbalance production and makeup of the cell wall. Using the "fiberglass" illustration, a boron deficient cell wall would be like grinding up the fiberglass sheets before laying them down and attempting to glue them together. Fiberglass (and cell walls) gets its strength from the perpendicular stands of fiber that make a thin but strong layer. Disrupting this structure weakens the entire bonding ability of the "glue" and the entire structure.



Fischer & Hecht-Buchholz, 1985 in Mineral Nutrition of Higher Plants, pg 384

As stated, severely deficient boron plants will also lose the structure of the "nutrient pipeline" (phloem), which will understandably have many adverse effects of improper nutrition, including disease pressure.


Pissarek, 1980, in Mineral Nutrition of Higher Plants, pg 385

Nitrogen

The excess of nitrogen is one of the most common causes of excess disease pressure in agriculture today. In many instances, it is not only the excess, but also an imbalance, especially earlier in the growing season when temperatures are normally cooler and wetter and lots of new tissue is being formed. Excess nitrogen is directly related to obligate types of parasitic fungi (rust & powdery mildew). The reason is that nitrogen is used in the production of amino acids and indirectly in the production of sugars. This is especially a problem when potassium is low. This causes an abundance of low molecular weight compounds (amino acids & sugars), with a lack of conversion of the compounds to more complex ones (protein & starch).

High levels of amino acids are also an invitation for sucking insects such as aphids. High amino acids are a result of high N and/or poor protein synthesis due to deficiencies of potassium (or zinc). Here again is demonstrated the importance of balance. Magnesium is an antagonist of potassium; therefore increased amounts will affect potassium levels, which effect protein formation, which is made worse with high N as demonstrated in the table below. In this test Cup-Shield lice on oak trees was monitored with different applications of K, Mg, P and N.

Effects of Fertilizers Applied on a Soil Low in Available Potassium on Infestation of Oak Trees by Cup-Shield Lice

	Fertilizer			
	K + Mg	N+P+K+Mg	Mg	N + P + Mg
# of lice/10 cm stem	0.72	0.82	4.32	8.78

Bruning, 1967, Mineral Nutrition of Higher Plants, pg. 455.

Nitrogen applications can also have an effect on soilborne pathogens such as take-all root rot disease in wheat and barley. This fungus as an optimal growth at pH 7.0 and higher, therefore is more of a problem on calcareous soils and is not a problem on acidic soils. However, in this case the form of N can affect the presence of this disease also. Fall applied ammonium N is rapidly nitrified into Nitrate and caused considerable more yield loss from take-all than the control with no nitrogen. However, spring applied ammonium N that resulted in the least amount of take all pressure. This was due to the lack of conversion to nitrate and also possible that it could have increased the solubility of silica (high pH).

High N applications also tend to result in lower silica contents simply because of the growth rate verses supply and the silica that is present is diluted more.

High N applications can also effect the production of phenolic compounds needed for lignin. As we will see latter, here the balance with copper becomes important.

However, facultative parasitic fungi and bacteria (fusarium & bacterial wilt) are actually suppressed by higher N levels. This higher N level is related to the reduction of tissue degradation, or senescence. However, if calcium is low during this high growth period, it is likely that the effect of higher N will be negated.

Potassium

The relation of potassium to disease resistance in plants is much less complex than nitrogen. (N suppresses facultative & promotes obligate). Increase rates of potassium availability has a positive suppression on both types of parasitic fungi. In many tests potassium increase is directly related to suppression of disease up to the optimal range. However, there is always a "but…". As shown in the calcium section, high applications of potassium with low levels of calcium can increase disease pressure. This is particularly important to note for high applications of potassium in preplant fertilizers as commonly done. Especially in soils where the type of clay present is not effective in potassium tie up and release, resulting in potassium "luxury feeding, coupled with high N, fast growth and cool soil temperatures could very well result in low calcium and excess disease pressure.

Other than this condition, potassium is an important factor in suppressing plant pest problems through nutrition.

Balance N & K applications are so important. As stated, N promotes the production of amino acids and sugars (by leaf area & photosynthesis). Potassium plays an important role in the conversion of these low molecular weight compounds (food for many diseases) into more stable, higher molecular weight compounds that have more to do with suppression of disease than feeding.

A high content of potassium is required for the enzymatic conversion of simple sugars produced by photosynthesis into starch.

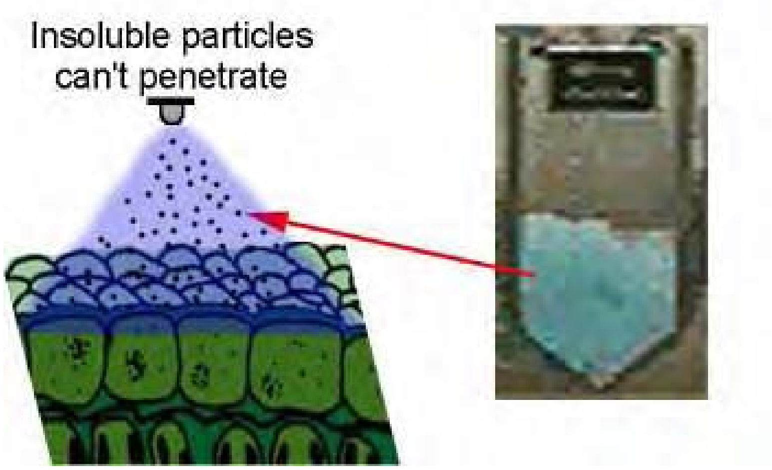
Lignin is another important component of cell wall structure to make a plant more resistant to disease. Potassium plays an indirect role in this process by blocking the production of enzymes that oxidizes (destroys) polyphenol compounds. Tests indicate that the levels of enzymes in potassium deficient plants can be from 80-100 times greater than in potassium sufficient plants.

Potassium in very important for the synthesis of protein (taking simple amino acids and combining them into larger forms) in many steps of production. The role of K is proven by the fact that soluble nitrogen compounds (amino acids, amides and nitrates) accumulate rapidly in plants deficient of K.

Copper

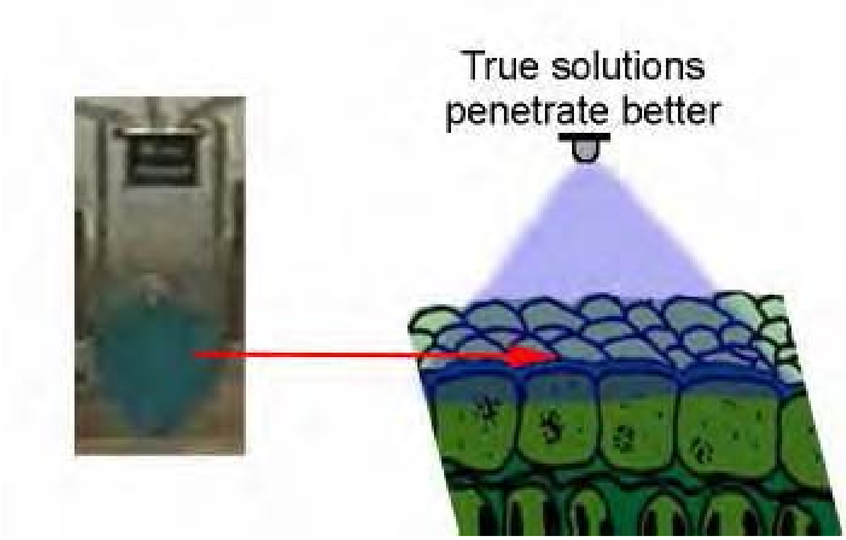
The role of copper in disease suppression is twofold. The first is direct suppression of disease on the surface of the leaf. This is in the form of fungicides. (Zinc and manganese compounds are also fungicides). However, this is a perfect subject to not only demonstrate how copper should be applied in order to effectively kill parasitic fungi, but also can show how ineffective and wasteful an improperly mixed foliar can be.

Copper-based fungicides are insoluble. Why? Simply because the disease causing organism lands on the surface of the leaf and in order for the fungicide to be effective, it must be present on the surface. Back to the foliar mixing demonstration:



Just like some copper based fungicides are made from copper hydroxide (OH = high pH) and therefore insoluble, this phosphate & copper compound is also insoluble. This foliar is now a copper fungicide spray.

For the purpose of studying the nutritional aspect of copper applications, the copper must enter the plant and become part of the biological system of the plant.



Copper containing enzymes are important for the production of polyphenol compounds that are involved in lignin biosynthesis (bio = life & synthesis = put together, put together by a living thing, the plant). Other compounds are also manufactured in the process; alkaloids, the formation of brown melanotic substance that are formed when tissues are wounded (i.e. apples and potatoes). These compounds can also act as phytoalexins, which inhibit spore germination and fungal growth.

Nutrient Management Summary

- High N (especially with cool weather) grows weak cells and an excess of amino acids.
- Low K causes sugars and amino acids stay simple and are not converted to starch (complex sugar) and protein (complex amino acids).
- Low Ca & B results in improper cell development, which results in the "leaking" of foods for disease and less "blocking" of disease penetration.
- Microelements, like Cu, are often overlooked in their importance but plants cannot produce the necessary "chemistry" to build healthy cells when these elements are deficient.

Biological & Microbiological Disease Management Systems

As science discovers more about the physiology and microbiology of plants, many disease suppressive functions become clearer and more possible to regulate to our advantage. This information/technology leads to several potentially valuable tools in disease management.

1. Leaf Microbial Management
2. Root Microbial Management
3. "Hypersensitive Response"

Leaf Microbial Management (epiphytic microorganisms)

The number, types and complexity of the microbes living on the surface of the leaves and stems is likely one of the most obscure fields of science in agriculture today. One gram of tissue of green plants like corn, oats, clover, alfalfa, garden grass, and other plants is the home to 1,540,000 to 99,200,000 microorganisms!

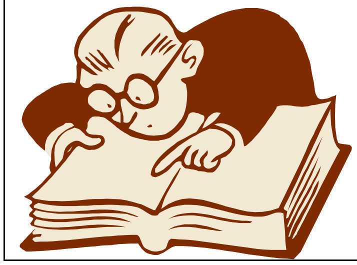
The problems of disease pressure arise when plants begin excreting compounds (or the external conditions are right) that feed parasitic organisms such as the many diseases we fight. The concept of Leaf Microbial Management (LMM) is simple; inoculate and maintain microorganisms on the leaf surface that compete/destroy disease causing organisms.

The introduction of organisms that exhibit antagonism towards foliar pathogens in this environment has been successful in controlling certain pathogens by several mechanisms, which include:

- Direct parasitism of the pathogen by the epiphyte
- Competition for nutrients and space
- The production of antibiotics and/or lytic enzymes by the antagonist
- Stimulation of a host resistance response.

One focus of plant disease control using biological agents has been the introduction of organisms capable of preempting the nutrient supply of a pathogen. It has been shown that if an established epiphytic (foliar) ecosystem is continuously supplied with a source of nutrition, it becomes difficult for a newly introduced pathogen to compete and growth of the pathogen is limited accordingly.

This can be obtained by the addition of specific organisms (usually bacteria) to consume the foodstuffs of potential disease organisms and/or to produce antibodies that suppress disease organisms. This positive effect can be further enhanced by supplying additional nutrition for the added microorganisms, supplying a better environment for the growth of these organisms and regulating the chemistry (pH) of this environment.



Research indicates that this concept of adding microbes that compete for "disease foodstuffs" can be further advanced into the addition of specific bacteria that utilized leaf (root) exudes to produce growth promoting substances such as plant hormones, *cytokines* (a protein "preserving" plant hormone) is especially desirable.

Compost tea (extract of specific composts) is likely one of the most promising systems of delivering a cost effective microbial suite for disease suppression by microbial competition and the production of "induced systemic resistance" compounds. This is a biological effect because research shows that the control of Phytophthora infestans on tomato leaves in the greenhouse was achieved using water extracts from composted organic wastes, but sterile-filtered or heat-treated extracts are ineffective.

An example of successful "competitive" microbiology can also be demonstrated in the field of fruit storage:

The effectiveness of supplying disease organism suppressing microbes can be illustrated in fruit storage. Damaged fruit supplies a host of "foods" (sugars) which disease causing organisms, left unchecked, can thrive on.

Pathogens such as *Penicillium expansum* or *Botrytis cinerea* enter the fruit through wounds, initiate infection and subsequently decay the fruit.

Microbes such as *Pseudomonas syringae* and various "fruit yeasts" can utilize the same foodstuffs and compete well enough to suppress the disease.

On the right is demonstrated the control of blue mold on wounded Red Bartlett pear using P. syringae strain L-59-66 (renamed as ESC11). After inoculation the fruit were stored for 30 days at 1°C and then for 7 days at 24°C.

(Wojciech Janisiewicz, USDA, Appalachian Fruit Research Station, Kearneysville, WV)
http://www.nysaes.cornell.edu/ent/biocontrol/pathogens/pseudomonas_s.html

Root Microbial Management (RMM)

The combination of soil and root microbial management is a large enough topic for another complete presentation. However, this is an important tool in managing disease. The concept is similar to that of LMM; inoculate, grow, induce, manage and supply the environment for the grow of "good" microbiology that out competes the disease.

These characteristics are found in many areas of agriculture. In literature, there are many recorded examples of the ability of one type of soil to suppress disease, while others can't. Some of this has to do with the physical and chemical properties of soils, while others are with rotation and biological properties. In France, research demonstrated that an inoculant could be made from disease suppressive soils and "transferred" to non-suppressive soils. In Holland, a researcher has successfully cultured the microbes from plants grown in "long rotation" fields and transferred them to "continuous" cropped fields with great success.

The concept of applying PGR (plant growth hormone) producing organisms is also a viable tool in agriculture. Of great interest is cytokinin producing microbes which help produce a continuous supply of the hormone to the leaves to prevent protein breakdown and leaf senescence.

Hypersensitive Response (HR)

Two basic systems of "self defense" are known for plants. These mechanisms are important tools in the overall system of disease management.

The Hypersensitive Response (HR) is a local resistance mechanism that is manifested as necrotic lesions (that is, regions of cell death) formed as a result of host cell death at the site of infection. The formation of these lesions helps to restrict pathogen growth and/or spread.

Systemic Acquired Resistance (SAR) is a systemic resistance to infection induced in the surrounding and distal, unaffected parts of the plant (i.e. resistance to infection in cells of the plant distant to the site of infection).

When a disease organism attacks a plant, several things can begin to happen;

1. The first defense that a plant will utilize is the response of dispersing new proteins. These proteins are called pathogenesis-related proteins. The purpose of the proteins is to restrict the growth of the pathogens.
2. The second response is that plants will induce synthesis of phytoalexins, which are anti-microbial compounds that restrict the growth of the pathogens. (SAR)
3. The final response that a plant will have against a pathogen is the production of hydrogen peroxide. This will kill the cells around the pathogen in order to restrict the growth of the pathogen. (HR)

All of this is still dependent of a TOTAL NUTRITIONAL APPROACH. A healthy plant must show a positive root growth in order to develop (and maintain) the proteins that were mentioned above. Experienced agronomists know that when the root system of a plant dies, it doesn't matter how many or what type of fungicides are used, the plant is still going to die. We have introduced the concept of utilizing microorganisms to produce cytokinins (protein preserving

PGR) on both the root and the leave. Tools such as these must all be utilized in unison to assure proper effect.

Conclusion

Unlike commercial pesticides (insecticides & fungicides) biocontrol methods are not as easy to use and most often are not 100% effective by themselves. However, the use of an "Integrated" system of pest/disease management is proving to be very effective. This would include:

1. Proper cell structure – Ca, B, K, Cu, Si with proper N management.
2. The specific bio-control microorganism(s)
3. Additional "food" – nutrients, enzymes, amino acids & sugars
4. Chemical Environment – pH monitoring (high = no fungi)
5. Physical Environment – Polymer for "housing"
6. Distribution – Proper spreading, film forming & humectants
7. Specific Compounds to induce SAR/ISR