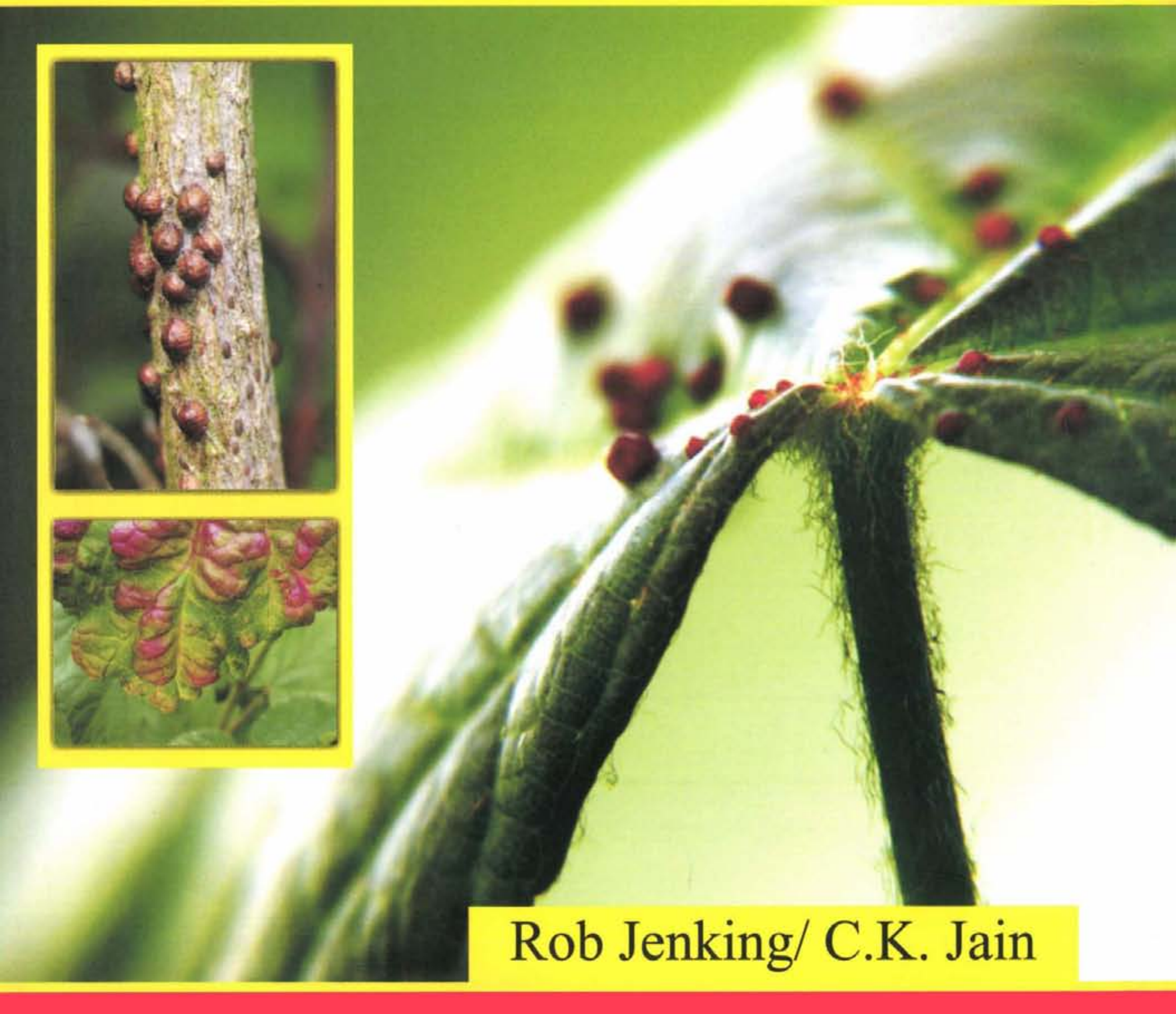
Advances in Soil-borne Plant Diseases



Rob Jenking/ C.K. Jain

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Preface

Plant diseases result when a susceptible host and a disease-causing pathogen meet in a favourable environment. If any one of these three conditions were not met, there would be no disease. Diseases may occur in natural environments, but they rarely run rampant and cause major problems. In contrast, the threat of disease epidemics in crop production is constant. The reasons for this are becoming increasingly evident. Soil-borne diseases result from a reduction of biodiversity of soil organisms. Restoring beneficial organisms that attack, repel, or otherwise antagonise disease-causing pathogens will render a soil disease-suppressive. Plants growing in disease-suppressive soil resist diseases much better than in soils low in biological diversity. Beneficial organisms can be added directly, or the soil environment can be made more favourable for them through use of compost and other organic amendments. Compost quality determines its effectiveness at suppressing soil-borne plant diseases.

There are two types of disease suppression: specific and general. Specific suppression results from one organism directly suppressing a known pathogen. These are cases where a biological control agent is introduced into the soil for the specific purpose of reducing disease incidence. General suppression is the result of a high biodiversity of microbial populations that creates conditions unfavourable for plant disease development. Soil pH, calcium level, nitrogen form, and the availability of nutrients can all play major roles in disease management. Adequate crop nutrition makes plants more tolerant of or resistant to disease. Also, the nutrient status of the soil and the use of particular fertilisers and amendments can have significant impacts on the pathogen's environment.

This book describes the characteristics of various soil-borne diseases of plants and the measures to prevent them. It provides a detailed description of the life of the pathogens, chemical and pesticidal means of regulation, taxonomic changes have been made in bacteria, fungi, nematodes and viruses; changing patterns of diseases and many recently reported diseases. This book should be useful to gardeners, landscape architects, florists, nurserymen, seed and fungicide dealers, pesticide applicators, cooperative extension agents and plant pathologists. It should also be a useful reference book for plant pathology classrooms and in some cases used as a textbook.

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Introduction to Soil-borne Plant Diseases

Soil-borne diseases result from a reduction of biodiversity of soil organisms. Restoring beneficial organisms that attack, repel, or otherwise antagonize disease-causing pathogens will render a soil disease-suppressive. Plants growing in disease-suppressive soil resist diseases much better than in soils low in biological diversity. Beneficial organisms can be added directly, or the soil environment can be made more favorable for them through use of compost and other organic amendments. Compost quality determines its effectiveness at suppressing soil-borne plant diseases. Compost quality can be determined through laboratory testing.

Plants can suffer from bacterial, viral and fungal attack just as we can ourselves. The organisms themselves (pathogens) are different, but at the microbial level the infection is much the same since one cell is as good a host as another. No matter which part of the plant is attacked the effect is usually to weaken or kill it. By infecting the leaves the plant's ability to produce its food is reduced. Some pathogens block the vessels in the stems which supply the leaves and by attacking the roots, the uptake of water and nutrients is reduced or stopped completely.When a plant is attacked by one of these microorganisms the damage caused provides an opportunity for the others to get in and it is the combined onslaught which deals the final blow. Also if it is under stress, such as through drought or poor nutrition it is more susceptible.

Sometimes the 'infection' is symbiotic where both organisms derive a benifit. A good example of this is the nitrogen fixing bacteria (Rhizobium) which reside in nodules on the roots of leguminous (pea family) plants, the plant provides food and protection, the bacteria takes nitrogen from the air and converts it to a form usable by the host. Also the Mycorrhizae are a whole Order of fungi which have a symbiotic relationship with plant roots. In other cases of interest to gardeners, the plant is not benefited but the changes caused produce more attractive features. This is what happens with Aucuba japonica where a viral infection produces the mottled leaves in the 'Variegata' variety. The Tulipomania craze in the 17th century was caused when 'Broken' varieties of tulips began to appear with streaked and mottled petals. This occurred at random and increased the desire and fascination for the bizarre effects. Prized examples were valued at more than "a mansion with servants", although it was not discovered until the early 20th century that viruses were to blame for the unusual colours and effects. In Holland, where the craze caused great hardship when it crashed in 1637, they now grow the pure forms with no streaks or frills.

Fungi are essential in breaking down dead organic matter to produce the humus which is needed for good soil structure—saprophytes. They do not have any chlorophyll so cannot use light to capture energy, instead they derive their energy by breaking down plant and animal material—alive or dead. They can also live in a symbiotic relationship, eg. the micorrhiza in the fine roots of conifers which cannot survive without them to take up vital nutrients. The widespread use of chemical control can damage the balance of these beneficial fungi and this forms part of the principals of Organic management. Lichens are an algae and a fungus growing together as a symbiotic conjunction, i.e., the fungus provides physical support for the algae and the algae produces food. There are some less welcome fungi which attack living plants and weaken or kill them—these are the ones which are mentioned in more detail here.

Viruses dwell inside the cells and cannot be treated with chemicals so affected plants must be destroyed (special microculture techniques may overcome the infection by taking cells from the growing tip, but this is restricted to the laboratory). There are no antibiotics for plants, so bacterial attacks, eg. fireblight, are untreatable as well. Fungi can be killed with chemicals without damaging the host because their growth habit is different, ie. they tend to grow on the plant and not in it, using root-like structures to extract nurishment.

Since killing the pathogens is difficult or impossible, "prevention is better than cure". By observing good hygiene when propogating and growing your plants, you can prevent a lot of diseases from taking hold.

- Destroy diseased plants, clear up dead leaves and other debris.
- As the spores can have tough outer coatings, do not add diseased material to the domestic compost heap as they do not usually achieve high enough temperatures to destroy them.
- Prune fruit trees and bushes regularly to keep an open structure allowing a good air flow and to remove damaged branches.
- Disinfect secateurs, saws or knives used for cutting out diseased branches with methylated spirits or a flame (a cigarette lighter comes in handy for this). Household bleach or other disinfectants can also be used as a dip for shears and clippers, including electric or petrol machines. This also helps when taking cuttings.

- Only use new or well-washed containers when growing cuttings and sowing seeds.
- Crop rotation in the vegetable plot will prevent a build up of disease.
- Space plants well apart especially crops where similar plants are growing together, to allow good air flow. Fungal diseases in particular, thrive in still, damp air and there is a greater chance for them to be transmitted to surrounding plants if they are in close proximity.
- Catching disease early is important so keep an eye out for it at all times.
- Plants are more susceptible to disease if they are not growing well. This can be due to poor soil, drought or both. So prepare the site well adding plenty of organic matter and give plants an occasional feed. As gardeners we are usually trying to grow plants which most likely are not native to the region or in a place they would not choose for themselves, so there is a greater probability that they could be under stress.

TYPES OF SOIL-BORNE PLANT DISEASES

Plant diseases result when a susceptible host and a disease-causing pathogen meet in a favorable environment. If any one of these three conditions were not met, there would be no disease. Many intervention practices (fungicides, methyl bromide fumigants, etc.) focus on taking out the pathogen after its effects become apparent. This publication emphasizes making the environment less disease-favorable and the host plant less susceptible.

Plant diseases may occur in natural environments, but they rarely run rampant and cause major problems. In contrast, the threat of disease epidemics in crop production is constant. The reasons for this are becoming increasingly evident. Dr. Elaine Ingham, a soil microbiologist and founder of Soil Foodweb Inc., describes the progression from undisturbed grassland—where a wide diversity of plants grow, their roots commingling with a wide diversity of soil organisms—to a field in row crops.

A typical teaspoon of native grassland soil would contain between 600- to 800-million individual bacteria that are members of perhaps 10,000 species. There are several miles of fungi, and perhaps 5000 species of fungi per teaspoon of soil. There are 10,000 individual protozoa split into three main groups, i.e., flagellates, amoebae and ciliates, and perhaps 1000 species of protozoa. There are 20 to 30 beneficial nematodes, which are members of as many as 100 species. Root-feeding nematodes are quite scarce in truly healthy soils. They are present, but in numbers so low that it is rare to find them. After only one plowing a few species of bacteria and fungi become extinct locally because the food they need is no longer put back in the system. But for the most part, all the suppressive organisms, all the nutrient cyclers, all the decomposers, all the soil organisms that rebuild good soil structure are still present and continue to try to do their jobs.

Why doesn't the limited food resources bother them more? A good savings account of organic matter has been built up in native grassland and native forest soil. The soil organisms use the organic matter they "put away" all those years when disturbance did not occur. ...But agriculture continues to mine soil organic matter and kill fungi by tilling. The larger predators are crushed, their homes destroyed. The bacteria go through a bloom and blow off huge amounts of that savings account organic-matter. With continued tillage the "policemen" (organisms) that compete with and inhibit disease are lost. The "architects" that build soil aggregates, are lost. So are the engineers, the larger organisms that design and form the larger pores in soil. The predators that keep bacteria, fungi and root-feeding organisms in line are lost. Disease suppression declines, soil structure erodes, and water infiltration decreases because mineral crusts form.

The decline can take 20 to 30 years to reach the point that most of the natural controls are finally lost and disease runs rampant. The speed with which the "edge" is reached depends on the amount of soil organic matter that was in the soil when it was first plowed, how often the soil was plowed and how much residue was added back. Additionally, how much variety was added back, and the inoculum base for the disease are also important. Certain diseases don't occur in some places because the disease hasn't reached them yet. But the instant the disease does arrive, it goes throughout he fields like a wildfire, because there are few natural competitors to stop it in the soil.

This progression of decline that Dr. Ingham describes leads to sick soils, and sick soils produce sick crops. As plants and soils have become sicker, growers have responded with newer and more powerful chemicals in an effort to kill off the problem pathogens. While it may seem the logical course of action, chemical intervention only serves to make things worse over time. Many pesticides reduce the diversity of soil life even further and select for resistant pathogens. This is the history of methyl bromide. Once this fumigant was highly effective if used only every five years. Today, on the same soils, it must be used much more frequently to keep the pathogens under control.

Until we improve the soil life we will continue on this pesticide treadmill. The general principle is to add the beneficial soil organisms and the food they need—the ultimate goal being the highest number and diversity of soil organisms. The higher the diversity, the more stable the soil biological system. These beneficial organisms will suppress disease through competition, antagonism, and direct feeding on pathogenic fungi, bacteria, and nematodes. We cannot restore the balance of organisms that was present under native, undisturbed circumstances, but we can build a new, stable balance of soil organisms that will be adapted to the altered soil conditions. This is a proactive plan that moves us toward the desired outcome of disease prevention.

STRATEGIES FOR CONTROL

There are two types of disease suppression: specific and general. Specific suppression results from one organism directly suppressing a known pathogen. These are cases where a biological control agent is introduced into the soil for the specific purpose of reducing disease incidence. General suppression is the result of a high biodiversity of microbial populations that creates conditions unfavorable for plant disease development. A good example of specific suppression is provided by a strategy used to control one of the organisms that cause damping off—Rhizoctonia solani. Where present under cool temperatures and wet soil conditions, Rhizoctonia kills young seedlings. The beneficial fungus Trichoderma locates then attacks Rhizoctonia through a chemical released by the pathogen. Beneficial fungal strands (hyphae) entangle the pathogen and release enzymes that dehydrate Rhizoctonia cells, eventually killing them. Introducing a single organism to soils seldom achieves disease suppression for very long. If not already present, the new organism may not be competitive with existing microorganisms. If food sources are not abundant enough, the new organism will not have enough to eat. If soil conditions are inadequate, the introduced beneficial organism will not survive. This practice is not sufficient to render the soil "disease suppressive"; it is like planting flowers in the desert and expecting them to survive without water. With adequate soil conditions, inoculation with certain beneficials should only be needed once.

Disease Suppressive Soils

A soil is considered suppressive when, in spite of favorable conditions for disease to occur, a pathogen either cannot become established, establishes but produces no disease, or establishes and produces disease for a short time and then declines. Suppressiveness is linked to the types and numbers of soil organisms, fertility level, and nature of the soil itself (drainage and texture). The mechanisms by which disease organisms are suppressed in these soils include induced resistance, direct parasitism (one organism consuming another), nutrient competition, and direct inhibition through antibiotics secreted by beneficial organisms. Additionally, the response of plants growing in the soil contributes to suppressiveness. This is known as "induced resistance" and occurs when the rhizosphere (soil around plant roots) is inoculated with a weakly virulent pathogen. After being challenged by the weak pathogen, the plant develops the capacity for future effective response to a more virulent pathogen. In most cases, adding mature compost to a soil induces disease resistance in many plants.

The level of disease suppressiveness is typically related to the level of total microbiological activity in a soil. The larger the active microbial biomass, the greater the soil's capacity to use carbon, nutrients, and energy, thus lowering their availability to pathogens. In other words, competition for mineral nutrients is high, as most soil nutrients are tied up in microbial bodies. Nutrient release is a consequence of grazing by protozoa and other microbial predators: once bacteria are digested by the predators, nutrients are released in their waste.

High competition—coupled with secretion of antibiotics by some beneficial organisms and direct parasitism by others—makes a tough environment for the pathogen. Our goal is to create soil conditions with all three of these factors present. Therefore, we want high numbers and diversity of competitors, inhibitors, and predators of disease organisms, as well as food sources on which these organisms depend. The food for beneficial organisms comes either directly or indirectly from organic matter and waste products from the growth of other organisms.

Limiting available nutrients is a key for geneıal suppression. With an abundance of free nutrients, the pathogen can prosper. Virtually any treatment to increase the total microbial activity in the soil will enhance general suppression of pathogens by increasing competition for nutrients. So, how does the plant survive without readily available nutrients? It does so through microbial associations with mychorrhizal fungi and bacteria that live on and near the roots. These microbes scavenge nutrients for the plant to use. In return the plant provides carbon in the form of sugars and proteins to the microbes. This symbiotic system supports the beneficial organisms and the plant, but generally excludes the pathogens that would attack the plant.

It should be noted that general suppression will not control all soil-borne diseases. Rhizoctonia solani and Sclerotium rolfsii, for example, are not controlled by suppressive soils—their large propagules make them less reliant on external energy or nutrient sources, and therefore, they are not susceptible to microbial competition. With these two pathogens, "specific" beneficial organisms such as Trichoderma and Gliocladium will colonize the harmful propagules and reduce the disease potential.

Mycorrhizal Fungi and Disease Suppression

Among the most beneficial root-inhabiting organisms, mycorrhizal fungi can cover plant roots, forming what is known as a fungal mat, The mycorrhizal fungi protect plant roots from diseases in several ways:

- By providing a physical barrier to the invading pathogen. A few examples of physical exclusion have been reported. Physical protection is more likely to exclude soil insects and nematodes than bacteria or fungi. However, some studies have shown that nematodes can penetrate the fungal mat.
- By providing antagonistic chemicals. Mycorrhizal fungi can produce a variety of antibiotics and other toxins that act against pathogenic organisms.
- By competing with the pathogen.

- By increasing the nutrient-uptake ability of plant roots. For example, improved phosphorus uptake in the host plant has commonly been associated with mychorrhizal fungi. When plants are not deprived of nutrients, they are better able to tolerate or resist disease-causing organisms.
- By changing the amount and type of plant root exudates. Pathogens dependent on certain exudates will be at a disadvantage as the exudates change.

In field studies with eggplant, fruit numbers went from an average of 3.5 per plant to an average of 5.8 per plant when inoculated with Gigaspora margarita mycorrhizal fungi. Average fruit weight per plant went from 258 grams to 437 grams. A lower incidence of Verticillium wilt was also realized in the mycorrhizal plants.

Protection from the pathogen Fusarium oxysporum was shown in a field study using a cool-season annual grass and mycorrhizal fungi. In this study the disease was suppressed in mycorrhizae-colonized grass inoculated with the pathogen. In the absence of disease the benefit to the plant from the mycorrhizal fungi was negligible. Roots were twice as long where they had grown in the presence of both the pathogen and the mycorrhizal fungi as opposed to growing with the pathogen alone. Great care was taken in this study to assure that naturally-occurring mycorrhizal species were used that normally occur in the field with this grass, and that their density on the plant roots was typical.

Crop Rotation and Disease Suppression

Avoiding disease buildup is probably the most widely emphasized benefit of crop rotation in vegetable production. Many diseases build up in the soil when the same crop is grown in the same field year after year. Rotation to a non-susceptible crop can help break this cycle by reducing pathogen levels. To be effective, rotations must be carefully planned. Since diseases usually attack plants related to each other, it is helpful to group vegetable rotations by family—e.g., nightshades, alliums, cole crops, cucurbits. The susceptible crop, related plants, and alternate host plants for the disease must be kept out of the field during the rotation period. Since plant pathogens persist in the soil for different lengths of time, the length of the rotation will vary with the disease being managed. To effectively plan a crop rotation, it is essential to know what crops are affected by what disease organisms.

In most cases, crop rotation effectively controls those pathogens that survive in soil or on crop residue. Crop rotation will not help control diseases that are wind-blown or insect vectored from outside the area. Nor will it help control pathogens that can survive long periods in the soil without a host—Fusarium, for example. Rotation, by itself, is only effective on pathogens that can overwinter in the field or be introduced on infected seeds or transplants. Of course, disease-free transplants or seed should be used in combination with crop rotation. The period of time between susceptible crops is highly variable, depending on the disease. For example, it takes seven years without any cruciferous crops for clubfoot to dissipate. Three years between parsley is needed to avoid damping off, and three years without tomatoes to avoid Verticillium wilt on potatoes.

A three-year crop rotation is the standard recommendation for control of black rot (Ceratocystis fimbriata), stem rot (Fusarium oxysporum), and scurf (Monilochaetes infuscans) in sweet potatoes. Rotations may include grasses, corn, and other cereals in the Southwest where Texas root rot (Phymatotrichum omnivorum) is a problem.

Table 1. Rotation periods to reduce vegetable soil-borne diseases.

Vegetable	Disease	Years w/o susceptible crop
Asparagus	Fusarium rot	8
Beans	Root rots	3–4
Cabbage	Clubroot	7
Cabbage	Blackleg	3–4
Cabbage	Black rot	2–3
Muskmelon	Fusarium wilt	5
Parsnip	Root canker	2
Peas	Root rots	3–4
Peas	Fusarium wilt	5
Pumpkin	Black rot	2
Radish	Clubroot	7

Plant Nutrients and Disease Control

Soil pH, calcium level, nitrogen form, and the availability of nutrients can all play major roles in disease management. Adequate crop nutrition makes plants more tolerant of or resistant to disease. Also, the nutrient status of the soil and the use of particular fertilizers and amendments can have significant impacts on the pathogen's environment.

One of the most widely recognized associations between fertility management and a crop disease is the effect of soil pH on potato scab. Potato scab is more severe in soils with pH levels above 5.2. Below 5.2 the disease is generally suppressed. Sulfur and ammonium sources of nitrogen acidify the soil, also reducing the incidence and severity of potato scab. Liming, on the other hand, increases disease severity. While lowering the pH is an effective strategy for potato scab, increasing soil pH or calcium levels may be beneficial for disease management in many other crops. Adequate levels of calcium can reduce clubroot in crucifer crops (broccoli, cabbage, turnips, etc.). The disease is inhibited in neutral to slightly alkaline soils (pH 6.7 to 7.2). A direct correlation between adequate calcium levels, and/or higher pH, and decreasing levels of Fusarium occurrence has been established for a number of crops, including tomatoes, cotton, melons, and several ornamentals. Soil pH, calcium level, nitrogen form, and the availability of nutrients can all play major roles in disease management.

Calcium has also been used to control soil-borne diseases caused by Pythium, such as damping off. Crops where this has proved effective include wheat, peanuts, peas, soybeans, peppers, sugarbeets, beans, tomatoes, onions, and snapdragons. Researchers in Hawaii reported reduction of damping off in cucumber after amending the soil with calcium and adding alfalfa meal to increase the microbial populations.

Nitrate forms of nitrogen fertilizer may suppress Fusarium wilt of tomato, while the ammonia form increases disease severity. The nitrate form tends to make the root zone less acidic. Basically, the beneficial effects of high pH are lost by using acidifying ammonium nitrogen. Tomato studies have shown that use of nitrate nitrogen in soil with an already high pH results in even better wilt control. Celery studies showed reduced Fusarium disease levels from using calcium nitrate as compared to ammonium nitrate. The nitrate nitrogen form also produced the lowest levels of Fusarium on chrysanthemums, king aster, and carnation.

It has long been known that the form of nitrogen fertilizer can influence plant disease incidence. Research is beginning to reveal why. Dr. Joe Heckman of Rutgers University showed that when grass roots absorbed nitrate nitrogen, an alkaline root zone condition was created. When the grass absorbed ammonium nitrogen, an acid root zone was created. The pathogen responsible for summer patch disease in turf thrives in alkaline soils. This finding supported the use of ammonium sulfate for grass. Research trials using ammonium sulfate reduced summer patch severity up to 75%, compared to using an equal rate of calcium nitrate. A more acid soil also fosters better uptake of manganese. Adequate manganese stimulated disease resistance in some plants. Research at Purdue University showed that uptake of ammonium nitrogen improved plant uptake of manganese and decreased take-all disease (Gaeumannomyces graminis var. tritici). Similar results were seen with Verticillium wilt in potatoes and stalk rot in corn.

Potassium fertility is also associated with disease management. Inadequate potash levels can lead to susceptibility to Verticillium wilt in cotton. Mississippi researchers found that cotton soils with 200 to 300 pounds of potassium per acre grew plants with 22 to 62% leaf infections. Soil test levels above 300 pounds per acre had from zero to 30% infection rate. High potassium levels also retard Fusarium in tomatoes. Severity of wilt in cotton was decreased by boosting potassium rates as well.

Phosphate can also be critical. Increasing phosphorus rates above the level needed to grow the crop can increase the severity of Fusarium wilt in cotton and muskmelon. In general, the combination of lime, nitrate nitrogen, and low phosphorus is effective in reducing the severity of Fusarium.

Compost and Disease Suppression

Compost has been used effectively in the nursery industry, in high-value crops, and in potting soil mixtures for control of root rot diseases. Adding compost to soil may be viewed as one of a spectrum of techniques—including cover cropping, crop rotations, mulching, and manuring—that add organic matter to the soil. The major difference between compost-amended soil and the other techniques is that organic matter in compost is already "digested." Other techniques require the digestion to take place in the soil, which allows for both anaerobic and aerobic decomposition of organic matter. Properly composted organic matter is digested chiefly through aerobic processes. These differences have important implications for soil and nutrient management, as well as plant health and pest management. Chemicals left after anaerobic decomposition largely reduce compost quality. Residual sulfides are a classic example.

Successful disease suppression by compost has been less frequent in soils than in potting mixes. This is probably why there has been much more research (and commercialization) concerning compost-amended potting mixes and growing media for greenhouse plant production than research on compost-amended soils for field crop production. Below is a table that outlines some of the (mostly) field research done on compost-amended soils and the effects on plant disease.

In some further research, University of Florida field trials showed disease suppressive effects of compost and heat-treated sewage sludge on snap beans and southern peas (black-eyed peas). The compost was applied at 36 or 72 tons per acre and the sludge at 0.67 and 1.33 tons per acre. Bush beans were planted six weeks after the organic treatments were applied and tilled in. After the bush beans were harvested, a second crop of southern peas was planted. A standard fertilizer program was used. Plant damage from ashy stem blight was given a rating of slight, moderate, or severe. Rhizoctonia root rot disease ratings were made using a scale from 0 to 10, where 10 represented the most severe symptoms.

Bean sizes from the compost treatment, at both application rates (36 and 72 T/ac), were larger and yields 25% higher than those from areas receiving no organic amendment. Ashy stem blight was severe in areas with no compost applied. The disease was reduced under the sludge treatment but almost eliminated where compost had been applied. Leaf wilting and leaf death were pronounced in that portion of the field where compost was not applied.