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Sustainable Management of Soil-borne Plant Diseases

Soil Systems Guide

Abstract: *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.*

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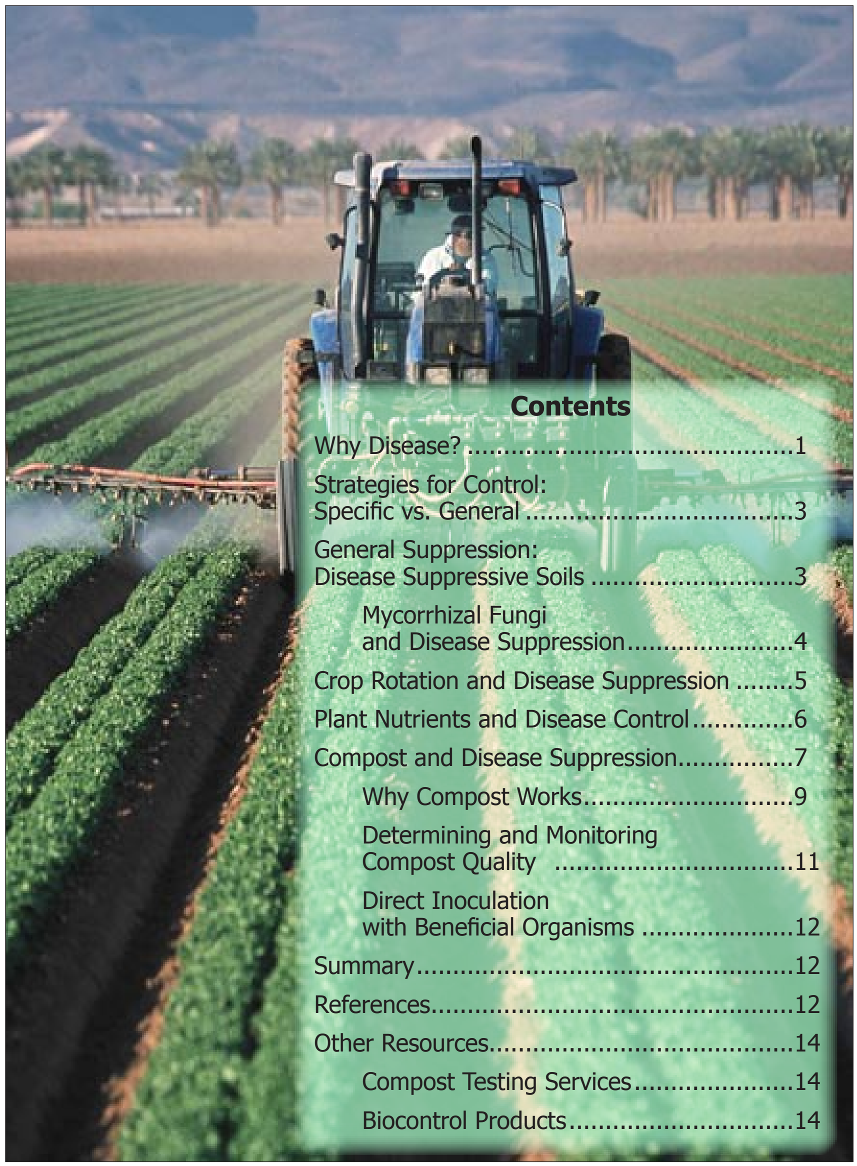

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Photo by Jeff Vanuga, USDA Natural Resources Conservation Service

Why Disease?

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.

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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.
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> 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.
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> 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 the fields like a wildfire, because there are few natural competitors to stop it in the soil (1).

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 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

Photo by Lynn Betts, USDA Natural Resources Conservation Service 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: Specific vs. General

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 diseases to develop.

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 Rhizoctonia through a chemical released by the pathogen, then attacks it. Beneficial fungal strands (hyphae) entangle the pathogen and release enzymes that dehydrate Rhizoctonia cells, eventually killing them (Figure 1). Currently, Trichoderma cultures are sold as biological seed treatments for damping off disease in several crops. For commercial sources of Trichoderma and other beneficial organisms, see the **Other Resources** section.

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.

Figure 1. Hyphae of the beneficial fungus Trichoderma wrap around the pathogenic fungus Rhizoctonia.

General Suppression: 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 (2).

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. (Using compost this way will be covered in detail below.)

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 (Figure 2)—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 (1).

As this discussion of competition suggests, limiting available nutrients is a key for general 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.

Figure 2. The nonpathogenic strain of Pythium fungus penetrates the pathogenic fungus Phytophthora.

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 (3). 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 (4). 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 (5).
- 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 (6).

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 (7).

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.

Table 1. Rotation periods to reduce vegetable soil-borne diseases (8).

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

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.

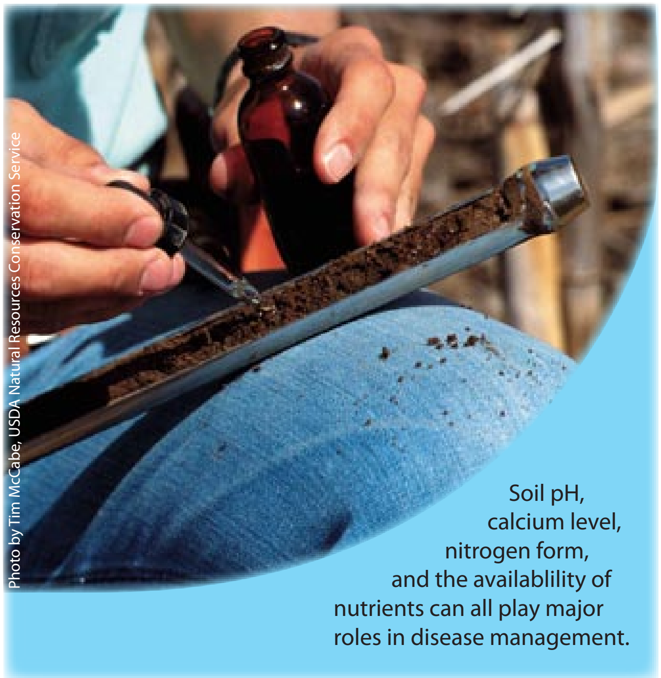
Plant Nutrients and Disease Control

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) (9). 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 (10).

Photo by Tim McCabe, USDA Natural Resources Conservation Service



Soil pH, calcium level, nitrogen form, and the availablility 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 (11). Researchers in Hawaii reported reduction of damping off in cucumbers after amending the soil with calcium and adding alfalfa meal to increase the microbial populations (11).

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 (12). 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 asters, and carnations (13).

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 (14). 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*) (14). 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 (15). High potassium levels also retard Fusarium in tomatoes (16). Severity of wilt in cotton was decreased by boosting potassium rates as well (17).

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 (10). 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 (21) 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

Compost Treatment and Disease Management

Vegetable	Pathogen/ Disease	Treatment	Comments
Alfalfa	"Clover tiredness"	Four years of treating fields with high-quality compost (no rate given).	Stand thickness and yield doubled, weeds crowded out (18).
Barley/Wheat	*Drysiphe graminis*/ Powdery mildew	Compost added to soil.	Disease incidence suppressed 95% when 1:1 soil:compost mixes used (19).
Beans (CA blackeye No. 5)	Rhizoctonia sp.	Compost added to soil at varying rates (36-72 tons/ acre).	Disease reduced 80% in areas with highest compost rates, 40% where intermediate rates applied. Control plots yielded 75 bushels/acre, compost plots yielded 200 bu/acre (20).
Cucumber	Sphaerotheca sp./ Powdery mildew	Young cucumber plants grown in soil/compost mix of variable rates.	1:1 soil:compost mix decreased PM by 20% over control; 1:3 mix decreased infection by 40% (19).
Pea (*Pisum sativum*)	Pythium sp./ Damping off	Seed treatment; seeds soaked in dilute compost extract, dried before sowing.	Peas seed-treated with compost extract germinated significantly better than untreated seed in soil artificially inoculated with *Pythium ultimum* (19).
Peppers	Phytophthora sp.	40 tons of compost per acre.	Compost in combination of hilling plant rows is best practice to reduce Phytophthora (20).
Soybeans	Phytophthora sp.	40 tons of compost per acre.	Control achieved (20).

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.

Southern peas as a second crop had greener foliage and larger plants under both rates of compost. Pea yields were significantly higher with 36 tons of compost. Where 72 tons of compost were used, yields were more than double the non-amended plots. With the sludge treatment, yields were comparable or slightly higher than where no amendment was added. Rhizoctonia root rot caused severe infections, plant stunting, and premature death where no compost was applied. Plants growing under the sludge treatment suffered severe root infection. Disease was reduced considerably as compost rates increased from 36 to 72 tons per acre (21).

Salinas, California, strawberry grower Tom Jones uses compost on his 125 acres of berries. Eight of those acres have had compost for two years and have just been certified organic. He uses microbially active, top-quality compost at an eight-ton per acre rate on the organic field and at five-tons per acre on the rest of the fields. Supplemented fish emulsion and other liquid fertilizers are supplied through a drip irrigation system.

Wisconsin fruit and vegetable farmers Richard DeWilde and Linda Halley have grown organic vegetables since 1991. University scientists are doing research on their farm to determine the effect of compost on health and productivity of vegetable crops and the soil microbial community. DeWilde makes quality compost on-farm from dairy and goat manure, applied at 10 to 15 tons per acre, realizing a 10% yield increase in one year. (22)

Why Compost Works

Compost is effective because it fosters a more diverse soil environment in which a myriad of soil organisms exist. Compost acts as a food source and shelter for the antagonists that compete with plant pathogens, for those organisms that prey on and parasitize pathogens, and for those beneficials that produce antibiotics. Root rots caused by Pythium and Phytophthora are generally suppressed by the high numbers and diversity of beneficial microbes found in the compost. Such beneficials prevent the germination of spores and infection of plants growing on the amended soil (23). To get more reliable results from compost, the compost itself needs to be stable and of consistent quality.

Systemic resistance is also induced in plants in response to compost treatments. Hoitink has now established that composts and compost teas indeed activate disease resistance genes in plants (22). These disease resistance genes are typically "turned on" by the plant in response to the presence of a pathogen. These genes mobilize chemical defenses against the pathogen invasion, although often too late to avoid the disease. Plants growing in compost, however, have these disease-prevention systems already running (22). Induced resistance is somewhat pathogen-specific, but it does allow an additional way to manage certain diseases through common farming practices.

It has become evident that a "one size fits all" approach to composting used in disease management will not work. Depending on feed stock, inoculum, and composting process, composts have different characteristics affecting disease management potential. For example, high carbon to nitrogen ratio (C:N) tree bark compost generally works well to suppress Fusarium wilts. With lower C:N ratio composts, Fusarium wilts may become more severe as a result of the excess nitrogen, which favors Fusarium (24). Compost from sewage sludge typically has a low C:N ratio.

Some of the beneficial microorganisms that re-inhabit compost from the outside edges after heating has subsided include several bacteria (Bacillus species, *Flavobacterium balustinum*, and various Pseudomanas species) and several fungi (Streptomyces, Penicillin, Trichoderma, and *Gliocladium verens*). The moisture content following peak heating of a compost is critical to the range of organisms inhabiting the finished compost. Dry composts with less than 34% moisture are likely to be colonized by fungi and, therefore, are conducive to Pythium diseases (24). Compost with at least 40 to 50% moisture will be colonized by both bacteria and fungi and will be disease suppressive (24). Water is typically added during the composting process to avoid a dry condition. Compost pH below 5.0 inhibits bacterial biocontrol agents (25). Compost made in the open air near trees has a higher diversity of microbes than compost made under a roof or in-vessel (3).

Three approaches can be used to increase the suppressiveness of compost. First, curing the compost for four months or more; second, incorporating the compost in the field soil several months before planting; and third, inoculating the compost with specific biocontrol agents (24). Two of the more common beneficials used to inoculate compost are strains of Trichoderma and Flavobacterium, added to suppress *Rhizoctonia solani*. *Trichoderma harzianum* acts against a broad range of soil-borne fungal crop pathogens, including *R. solani*, by production of anti-fungal exudates. See the **Other Resources** section for sources of commercial preparations.

The key to disease suppression in compost is the level of decomposition. As the compost matures, it becomes more suppressive. Readily available carbon compounds found in low-quality, immature compost can support Pythium and Rhizoctonia. As these compounds are reduced during the complete composting process, saprophytic growth of these pathogens is dramatically slowed (26). Beneficials such as *Trichoderma hamatum* and *T. harzianum*, unable to suppress Rhizoctonia in immature composts, are extremely effective when introduced into mature composts.

Microbiologist Patricia Millner and technician Michael Bzdil collect compost samples and gather data on temperature and moisture content.

Photo by Stephen Ausmus, USDA Agricultural Research Service

For Pythium suppression, there is a direct correlation between general microbial activity, the amount of microbial biomasss, and the degree of suppression. Pythium is a nutrient-dependent pathogen with the ability to colonize fresh plant residue, especially in soil that has been fumigated to kill all soil life. The severity of diseases caused by Pythium and *R. solani* relates less to the inoculum density than to the amount of saprophytic growth the pathogen achieves before infection (27). Consequently, soils that are antagonistic to saprophytic growth of Pythium—such as soils amended with fully decomposed compost—will lower disease levels.

Rhizoctonia is a highly competitive fungus that colonizes fresh organic matter (28). Its ability to colonize decomposed organic matter is decreased or non-existent. There is a direct relationship between a compost's level of decomposition and its suppression of Rhizoctonia—again pointing to the need for high-quality, mature compost. Like immature compost, raw manure is conducive to diseases at first and becomes suppressive after decomposition. In other words, organic amendments supporting high biological activity (i.e., decomposition) are suppressive of plant-root diseases, while raw organic matter will often favor colonization by pathogens.

Determining and Monitoring Compost Quality

It is clear that compost's maturity is a key factor in its ability to suppress disease. The challenge involved in achieving and measuring that maturity is the primary reason that compost is not more widely used. Certainly, immature compost can be used in field situations, as long as it is applied well ahead of planting, allowing for eventual stabilization. However, good disease suppression may not develop due to other factors. For example, highly saline compost actually enhances Pythium and Phytophthora diseases unless applied months ahead of planting to allow for leaching (24).

Dr. Harry Hoitink at Ohio State University has pioneered much of the work associated with disease suppressive composts. He notes that success or failure of any compost treatment for disease control depends on the nature of the raw product from which the compost was prepared, the maturity of the compost, and the composting process used. Failure to assess compost quality may be responsible for some of the failures in using compost for disease suppression (29). High-quality compost should contain disease-suppressive organisms and mycorrhizal innoculum (30). Furthermore, high-quality compost should contain very few if any weed seeds.

For more compost information, call and request the ATTRA publication **Farm-Scale Composting Resource List**.

This resource list is also available on our Web site, www.attra.ncat.org.

Several companies offer compost quality testing. Some of these also offer training on how to produce disease-suppressive compost. BBC Laboratories (31) offers a pathogen inhibition assay. This assay can determine the ability of your compost sample to directly inhibit specified soil-borne pathogens, including Fusarium, Phytophthora, Pythium, and Rhizoctonia. Each assay costs $75 and tests 12 replicates of your compost compared to 12 replicates of a control where the disease organism is uninhibited. They test for a number of other pathogens in addition to those mentioned above. They can test compost for microbial functional groups such as anaerobes, aerobes, yeasts, molds, actinomycetes, pseudomanads, and nitrogen-fixing bacteria. Their diversity analysis test looks at how many different kinds of organisms exist within each functional group. This information provides insight into how diverse the microbial populations in your compost are. They also test for compost maturity, which determines possible toxicity of immature compost to plants. Visit their Web site or call for more details. (See **Other Resources**.)

Midwest Biosystems (32) offers a grading system for compost quality. Their compost grades range from A to D, with A being disease suppressive. From your submitted sample they will test for sulfates and sulfides, pathogens, nitrogen forms, C:N ratio, seed germination, pH, conductivity, redox potential, and sodium and moisture levels. This test costs $30 per sample. An additional test for aerobic plate count and seed germination costs $10. Compost grades are assigned based on these tests. For a compost to grade A it must contain 600 to 900 ppm nitrates, no sulfides, meet all lab test guidelines, have a pH from 7.0 to 8.1, and have a 70 to 100% seed germination rate in pure compost.

Soil Foodweb, Inc. (33) offers microbial assays including microorganism diversity and biomass. They will comment on the disease suppressiveness of a compost sample based on their performance database for highly productive compost and the plant you are planning to put the compost on. Call or visit their Web site for prices and sampling instructions.

Direct Inoculation with Beneficial Organisms

There are a number of commercial products containing beneficial, disease-suppressive organisms. These products are applied in various ways—including seed treatments, compost inoculants, soil inoculants, and soil drenches. Among the beneficial organisms available are Trichoderma, Flavobacterium, Streptomycetes, Gliocladium spp., Bacillus spp., Pseudomonas spp., and others. A partial list of these products can be found in the **Other Resources** section. These companies will send you their product and technical information upon request. Consider your cost and overall soil health before trying these products. Dr. Elaine Ingham of the Soil Foodweb offers a perspective on using soil inoculants. The essence of her perspective is in the following paragraph.

Trichoderma and Gliocladium are effective at parasitizing other fungi, but they stay alive only as long as they have other fungi to parasitize. So, these fungi do a good job on the pathogenic fungi that are present when you inoculate them, but then they run out of food and go to sleep. In soils with low fungal biomass (soils with low organic matter and plenty of tillage) these two beneficials have nothing to feed on. Compost is a great source of both the organisms and the food they need to do their jobs. A great diversity of bacteria, fungi, protozoa and beneficial nematodes exists in good compost (4).

Read more of Dr. Ingham's commentary on the Soil Foodweb Web site, <www.soilfoodweb.com>, under the products section.

Summary

Soil-borne diseases result from a reduction in the biodiversity of soil organisms. Restoring important beneficial organisms that attack, repel, or otherwise antagonize disease-causing soil organisms will reduce their populations to a manageable level. Beneficial organisms can be added directly, or the soil environment can be made more favorable for them with compost and other organic amendments. Compost quality determines its effectiveness at suppressing soil-born plant diseases. Compost quality can be determined through laboratory testing.

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32) Midwest Bio-Systems. See Compost Testing Services section below.

33) Soil Foodweb. See Compost Testing Services section below.

Other Resources

Compost Testing Services

BBC Laboratories, Inc.
1217 North Stadem Drive
Tempe, AZ 85281
480-967-5931
480-967-5036 FAX
Contact: Vicki Bess
http://www.bbclabs.com
info@bbclabs.com

Midwest Bio-Systems
28933—35E Street
Tampico, IL 61283
815-438-7200
815-438-7200 FAX

Soil Foodweb, Inc.
1128 NE Second Street
Suite 120
Corvallis, OR 97330
541-752-5066
541-752-5142 FAX
http://www.soilfoodweb.com
info@soilfoodweb.com

Biocontrol Products

The following is a partial list of soil inoculum and biocontrol products available for control of soil-borne diseases on a variety of plants. For a more complete list see the Web site <http://www.oardc.ohio-state.edu/apsbcc/> and click on "product list."

Companion®
Growth Products
P.O. Box 1259
Westmoreland Avenue
White Plains, NY 10602
800-648-7626
http://www.growthproducts.com
info@growthproducts.com

Liquid drench containing Bacillus subtilis *GB03 for horticultural crops at seeding or transplanting or as a spray for turf (EPA experimental use permit, see label). Target pathogen/disease is Rhizoctonia, Pythium, Fusarium and Phytophthora*

Kodiak™, Kodiak HB, Kodiak FL
Gustafson, Inc.
1400 Preston Road
Plano, TX 75093
800-248-6907
972-985-8877

Dry powder formulation of Bacillus subtilis *for control of* Rhizoctonia solani, *Fusarium spp., Alternaria spp., and Aspergillus spp. attacking roots of cotton and legumes. Can be added to a slurry or mixed with a chemical fungicide for commercial seed treatment.*

Intercept™
Soil Technologies Corp.
2103 185th Street
Fairfield, IA 52556
641-472-3963
800-221-7645
http://www.soiltechcorp.com/intercept
info@soiltechcorp.com

A seed inoculant of Pseudomonas cepacia *for control of* Rhizoctonia solani, *Fusarium spp., Pythium sp. in corn, vegetables, and cotton.*

NOGALL™
New BioProducts, Inc.
4272 N.W. Pintail Place
Corvallis, OR 97330
541-752-2045
http://www.newbioproducts.com

Agrobacterium radiobacter *strain K-84 for control of crow gall disease caused by* Agrobacterium tumefaciens *in fruit, nut, and ornamental nursery stock. Used as a dip or spray for root, stems, or cuttings.*

Mycostop® / Mycostop Mix
Ag-Bio Development, Inc.
9915 Raleigh St.
Westminster, CO 80030
303-469-9221
877-268-2020
303-469-9598 FAX
http://www.agbio-inc.com
info@agbio-inc.com
Streptomycetes soil drench for suppression of Fusarium, Alternaria, and Phomopsis. Mycostop mix used for seed treatment.

RootShield®
Bioworks, Inc.
122 North Genesse Street
Geneva, NY 14456
315-781-1703
800-877-9443
http://www.bioworksinc.com
Trichoderma fungus for suppression of Pythium, Rhizoctonia solani, *and Fusarium spp. Applied as granules or wettable powder mixed with soil or potting medium or as a soil drench. Crops include trees, shrubs, transplants, all ornamentals, cabbage, tomatoes, and cucumbers.*

Soil Guard®
Certis-USA, LLC
9145 Guilford Road, Suite 175
Columbia, MD 21046
301-604-7340
800-250-5024
http://www.certisusa.com
mmayer@certisusa.com
Gliocladium virens *GL-21 for damping-off and root rot pathogens especially* Rhizoctonia solani *and Pythium spp. of ornamental and food crop plants grown in greenhouses, nurseries, homes, and interior-scapes. Sold as granules.*

System 3®
Helena Chemical Company
225 Schilling Blvd.
Collierville, TN 38017
901-761-0050
http://www.helenachemical.com
Bacillus subtilis *GB03 plus chemical pesticides. Used as a dust seed treatment for Fusarium,* Rhizoctonia solani, *and Pythium in the planter box for seedling pathogens of barley, beans, cotton, peanuts, peas, rice, and soybeans.*

T-22-HC
Bioworks, Inc.
122 North Genesee Street
Geneva, NY 14456
315-781-1703
http://www.bioworksinc.com
Trichoderma huzianum *Rifai strain KRL-AG2 for control of Pythium spp.,* Rhizoctonia solani, *Fusarium spp., and* Sclerotinia homeocarpa *in bean, cabbage, corn, cotton, cucumber, peanut, potato, sorghum, soybean, sugarbeet, tomato, turf, and greenhouse ornamentals. Applied as in-furrow granules, broadcast to turf, mixed with greenhouse soil, or mixing powder with seeds in the planter box or in commercial seed treatment.*

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The electronic version of **Sustainable Management of Soil-borne Plant Diseases** is located at:
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http://www.attra.org/attra-pub/soilborne.html
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