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Crop Rotations for Managing Soil-borne Plant Diseases

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Soil-borne diseases result from the reduction of the biodiversity of soil organisms. Restoring beneficial organisms that attack, repel, or 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. Although crop rotation reduces the risk of many row crop and cereal diseases, it does not eliminate them. Small amounts of the disease organism may persist in the soil or crop refuse over extended periods. In addition, crop rotation does not affect disease organisms that survive on or in the seed, such as the cereal smuts. Crop rotation also does not affect disease organisms that blow in from the south, such as the cereal rusts.

Key words: soil pH, soil-born, crop rotations

INTRODUCTION

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 attacking/eliminating the pathogen after its effects become apparent. This publication puts emphasis on 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.

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*. Under cool temperatures and wet soil conditions, *R. solani* kills young seedlings. The beneficial fungus *Trichoderma* sp. attacks *R. solani* through a chemical released by the pathogen. Beneficial fungal strands (hyphae) entangle the pathogen and release enzymes that dehydrate *R. solani* cells, eventually killing them (Figure 1). Currently, *Trichoderma sp*. cultures are available as commercial products against the damping off disease of several crops.

Introducing a single organism into the soil seldom achieves disease suppression for very long. If not already present, the new organism may not be competitive among the 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".

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, either it establishes but produces no disease, or it establishes and produces disease for a short time and then declines (Schneider, 1982). Suppressiveness is linked to the types and amount/concentration 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,

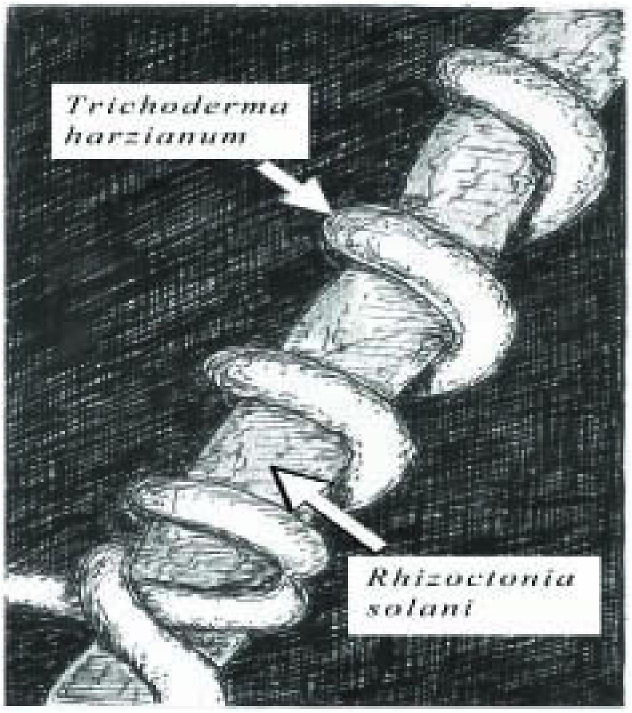

Figure 1. Hyphae of the beneficial fungus Trichoderma wrap around the pathogenic fungus Rhiozoctonia.

direct parasitism 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 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 into the 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 for carbon, nutrients, and energy, thus lowering their availability to pathogens (Dick and Tisdale, 1938). 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 (Ingham, 1998).

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. 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 (Granatstein,1998). To control these two pathogens, “specific” beneficial organisms such as *Trichoderma* sp. and *Gliocladium* sp. will colonize the harmful propagules and reduce the potential inoculum.

Soilborne diseases

Sclerotinia sclerotiorum (white mold)

This fungus attacks many broadleaf crops. Sunflowers are most susceptible. Dry beans, mustard, canola, lentils and safflower are highly susceptible when grown under irrigation or when the growing season is wet. Alfalfa, field peas, potatoes and garbanzo beans also are susceptible, but severe infections are less common than on highly susceptible crops. Infections in semileafless field peas, flax or buckwheat are rare in North Dakota Low levels of *Sclerotinia* are sufficient to maintain a population of the fungus in the soil and cause problems for the next highly susceptible crop. Ideally, all susceptible crops should be in a fouryear or longer rotation, with no other highly susceptible crop in the rotation. It may be necessary to avoid susceptible crops for five or six years on severely infested land. An example of a severe infestation would be a sunflower field that had over 10 percent Sclerotinia stalk rot (Maronek, 1981). If *Sclerotinia* is not at high levels, a fouryear rotation is still desirable to prevent its buildup. The best rotation crops for *Sclerotinia* control are small grains, grasses, corn, and sorghum, as these are not host crops for *Sclerotinia*. Many broadleaf weeds are susceptible, including wild mustard, marsh elder, lambsquarters, pigweed, and Canada thistle; they must be controlled when growing nonhost crops.

Specifically for sunflower, *Sclerotinia* attacks the crop in two ways (mention clearly which are the two ways)Sclerotia (hard, black fungus bodies) survive many years in the soil and may germinate to infect sunflower roots, resulting in a wilt disease which is also called basal stalk rot. Wilt occurs whenever sunflower is planted on *Sclerotinia*-infested land. When soil moisture is high for one to two weeks, the sclerotia form tiny mushroomlike structures (apothecia) that produce millions of airborne spores. These spores can infect the senescing flower parts of dry beans, canola, lentils, safflower, soybeans, field peas and garbanzo beans. They also can produce head rot and middle stalk rot in sunflower. Spores for these infections may come from the same field or a nearby field that has sclerotia on or near the soil surface, regardless of the current crop being grown in that field. Thus, *Sclerotinia*-free fields may become infested as a result of airborne spore infections of susceptible crops or weeds; in some years this can be a very important means of spread. Favorable weather conditions for spore formation do not occur every year. Excellent rotations will not prevent *Sclerotinia* from occurring in a field if the disease organism is introduced into clean fields by planting infested seed. Sclerotia can may mix with the seed at harvest. Planting certified seed reduces does not eliminate the danger of introducing *Sclerotinia* into clean fields.

***Verticillium* sp.**

Sunflowers should not be rotated with potatoes, since both crops are susceptible to this disease *Verticillium*-tolerant sunflower hybrids can support a population increase of *Verticillium* that could affect a subsequent potato crop. Potato varieties differ in their susceptibility to *Verticillium*: Kennebec is very susceptible, Russet Burbank is susceptible and Reddale is resistant. Potato crops should be grown at least three years apart. *Verticillium* also can be tuberborne on potato, so disease-free seed sources are important. Safflower also is susceptible to *Verticillium*, especially when grown under irrigation. Alfalfa is susceptible to *Verticillium* and should not be rotated with potatoes or sunflower unless separated by a minimum of three years.

***Plasmopara halstedii* (downy mildew of sunflower).**

This disease organism survives up to 14 years in the soil Schneider, 1982). Crop rotations are not suitable for its control, and currently available hybrids are not resistant to all races. Metalaxyl (Allegiance), Mefenoxam (Apron XL) or oxadixyl (Anchor) seed treatments have been used to protect against infection. Recently, the downy mildew fungus developed resistance to metalaxyl, mefenoxam and oxadixyl (Jones et al., 1989). New seed treatments for sunflower downy mildew control are under development.

***Rhizoctonia* sp. (seedling blight and root rot)**

The *Rhizoctonia* fungus is favored by warm, moist soils and causes seedling blight of sugarbeets, dry beans, soybeans, flax and many other crops . *Rhizoctonia* sp. may also infect seedlings when germination is delayed by cool, wet soils. It also causes a root rot of alfalfa, dry beans, soybeans and sugarbeets and black scurf of potato. However, no strain of *Rhizoctonia* infects all of these crops. Some common strains in North Dakota are designated AG22, AG3, and AG4. AG22 infects sugar-beet and results in root and crown rot, and it also causes a root rot of dry bean and soybean; sometimes it also causes a seedling blight of sugarbeet. AG3 is primarily a pathogen of potato and causes black scurf. The AG3 strain that attacks potato is both soilborne and tuberborne, so diseasefree seed sources and crop rotation are important for potato culture. AG4 is not so selective; it can cause seed rot, seedling blight and occasionally root rot of sugarbeets, plus similar diseases in alfalfa, dry beans, soybeans and canola. Growers should avoid short rotations between sugarbeets and dry beans or soybeans. Crops susceptible to the same strain or strains of *Rhizoctonia* should not be grown more often than once every three years.

***Aphanomyces cochlioides* (seedling blight and root rot of sugarbeet)**

A. cochlioides is a severe disease of sugarbeet that occurs on wet or waterlogged soils during warm weather. Extremely wet conditions in some areas during the summers of 1993, 1997, and 1998 favored *Aphanomyces,* especially in southern Minnesota. The fungus produces spores which survive over 20 years in the soil, making it almost impossible to control by rotation. It also survives on pigweed, kochia and lambs-quarters. Infested fields may need a better drainage system to avoid severe *Aphanomyces* damage in warm wet years. *Aphanomyces* tolerant hybrids and seed pelleted with Tachigaren fungicide is the best way to manage the disease in severely infested fields.

***Streptomyces* spp (Potato scab)**

The potato scab fungus is soilborne and survives many years in the soil. Scab is a common problem of garden potato but rather uncommon in commercial potatoes. If potatoes are planted in infested fields, the disease is best controlled by the use of resistant varieties. Do not use animal manure on fields where potatoes are grown in the rotation, as animal manure can increase the scab disease potential.

Heterodera schachtii

The sugarbeet nematode has not been reported in the Red River Valley of Minnesota and North Dakota in recent years, but it has been reported in the Red River Valley of Manitoba Canola is a host of the sugarbeet nematode and should **not** be grown in rotation with sugarbeets ; if it is grown in rotation, it should be equated to sugarbeet in the rotation sequence for purposes of determining sugarbeet rotation intervals.

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 (Ingham, 1991). 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 (Maronek, 1981).

• By providing antagonistic chemicals. Mycorrhizal fungi can produce a variety of antibiotics and other toxins that act against pathogenic organisms.

• 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 (Matsubara et al.,1995). 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 (Newsham et al., 1995).

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. . 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(Table 1). 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 recogni-

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

Vegetable	Disease	Years w/o susceptible crops
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

ized 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 S- and NH4-sources, 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) (Campbell et al.,1990). 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 (Jones et al., 1989).

Calcium has also been used to control soil-borne diseases such as damping off caused by Pythium, . Crops where this has proved effective include wheat, peanuts, peas, soybeans, peppers, sugarbeets, beans, tomatoes, onions, and snapdragons (Ko and Kao,1989). 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 (Ko and Kao,1989).

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 (Woltz and Jones, 1973). 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 (Woltz and Ebgelhard, 1973). It has long been known that the form of nitrogen fertilizer can influence plant disease incidence.

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 (Growth Tech Communications,1996). 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*) (Growth Tech Communications,1996).
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 (Obrien-Wray,1995). High potassium levels also retard Fusarium in tomatoes (Foster and Walker,1947). Severity of wilt in cotton was decreased by boosting potassium rates as well (Dick and Tisdale, 1938). 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 (Jones et al., 1989). In general, the combination of lime, nitrate nitrogen, and low phosphorus is effective in reducing the severity of Fusarium.

In particular, nutrients could affect the disease tolerance or resistance of plants to pathogens. However, there are contradictory reports about the effect of nutrients on plant diseases and many factors that influence this response are not well understood. This review article summarizes the most recent information regarding the effect of nutrients, such as N, K, P, Mn, Zn, B, Cl and Si, on disease resistance and tolerance and their use in sustainable agriculture. There is a difference in the response of obligate parasites to N supply, as when there is a high N level there is an increase in severity of the infection. In contrast, in facultative parasites at high N supply there is a decrease in the severity of the infection. K decreases the susceptibility of host plants up to the optimal level for growth and beyond this point there is no further increase in resistance. In contrast to K, the role of P in resistance is variable and seemingly inconsistent

Table 2. 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 (Logsdon, 1995).
Barley/Wheat	*Drysiphe graminis* / Powdery mildew	Compost added to soil.	Disease incidence suppressed 95% when 1:1 soil:compost mixes used (Trankner, 1992).
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 (Hudson, 1994).
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% (Trankner, 1992).
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* (Trankner, 1992).
Peppers	Phytophthora sp.	40 tons of compost per acre.	Compost in combination of hilling plant rows is best practice to reduce Phytophthora (Hudson, 1994).
Soybeans	Phytophthora sp.	40 tons of compost per acre.	Control achieved Hudson, (1994).

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. Above is Table 2 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 ((Ozores-Hampton et al., 1994)) 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. 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 was 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 (Ozores-Hampton et al., 1994)

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 (Harrison and Frank , 1999). To get more reliable results from compost, the compost itself needs to be stable and of consistent quality.

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 (Goldstein ,1998). 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 (Goldstein, 1998). 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 (Goldstein, 1998). 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. (Hoitink et al.,1991).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 (Hoitink et al.,1991).Compost with at least 40 to 50% moisture will be colonized by both bacteria and fungi and will be disease suppressive (Hoitink et al.,1991).Water is typically added during the composting process to avoid a dry condition. Compost pH below 5.0 inhibits bacterial biocontrol agents (Hoitink et al.,1991). Compost made in the open air near trees has a higher diversity of microbes than compost made under a roof or in-vessel (Granatstein,1998).

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 (Hoitink et al.,1991).Two of the more common beneficial 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 exudatesThe 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 (Cook and Baker, 1983). Beneficials such as *Trichoderma hamatum* and *T. harzianum*, unable to suppress Rhizoctonia in immature composts are

extremely effective when introduced into mature composts. 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 (Cook and Baker, 1983). 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 (Chung et al., 1988). 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

The challenge involved in achieving and measuring that maturity is the primary reason that compost is not used more widely. 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 (Hoitink et al.,1991).According to Hoitink (Ko and Kao,1989)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. (Hoitink,1986). High-quality compost should contain disease-suppressive organisms and mycorrhizal innoculum (Sances and Ingham,1997) and very few if any weed seeds. (BBC Laboratories (See Compost Testing Services section below.) offers a pathogen inhibition assay Using this assay can determine the ability of your compost sample to directly inhibit specified soil-borne pathogens, including Fusarium, Phytophthora, Pythium, and Rhizoctonia.

Soil PH management

Soil pH or soil reaction is an indication of the acidity or alkalinity of soil Activity increases as the pH value decreases. Soil pH also plays an important role in volatization losses. Ammonium in the soil solution exists in equilibrium with ammonia gas (NH_3). The equilibrium is strongly pH dependent. The availability of the micronutrients manganese (Mn), iron (Fe), copper (Cu), zinc (Zn), and boron (B) tend to decrease as soil pH increases. The exact mechanisms responsible for reducing availability differ for each nutrient, but can include formation of low solubility compounds, greater retention by soil colloids (clays and organic matter) and conversion of soluble forms to ions that plants cannot absorb. Molybdenum (Mo) behaves counter to the trend described above. Plant availability is lower under acid conditions.

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. 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 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 (Ingham, 1991).

Conclusion

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.
Soils tend to acidify over time, particularly when large applications of NH_4^+ based fertilizers are used or there is a high proportion of legumes in the rotation. So, a soil

with an optimum pH today may be too acid or alkaline a decade from now, depending on producer land management.

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