Compost Use for Disease Suppression

Harry A.J. Hoitink

**Professor Emeritus, Dept. of Plant Pathology,
The Ohio State University, Wooster, OH**

One of the most appealing attributes of compost is its potential to suppress plant diseases by improving the biological health of the soil. "Healthy soils" indeed produce "healthy plants." In general, compost amended soils do not eliminate plant pathogens; but, when organic amendments are effective in controlling plant diseases, pathogens do not cause economically important losses. Years of scientific study and practical breakthroughs by growers have removed much of the mysticism from this field of biological control. This section explains how and why compost and other organic amendments control plant diseases and what factors you can manage to improve predictability and efficacy of organic amendment-mediated disease suppression.

History of organic amendment use to suppress plant diseases

Farmers have used composts for thousands of years to maintain soil quality and produce healthy plants. During the 1930's, the first tests were performed with manure to control an epidemic caused by a soil-borne disease in cotton. The manure increased cotton yields and decreased the severity of Phymatotrichum root rot of cotton, even though some roots still were affected by the disease. The scientists speculated that some beneficial microorganisms on plant roots competed with plant pathogens while they produced antibiotics against them and in some cases killed plant pathogens. It was recognized even then that there was interaction between the crop and the organic amendment that might play a role in this "muck and magic" biological control of plant diseases. Only recently have these ideas been explained scientifically through published research.

Large scale disease control with compost applications began during the 1950's when the nursery industry in the US and Australia developed lower cost alternatives to peat from tree barks for use in potting mixes and ground beds for the production of woody ornamentals. Several growers found that composted bark could suppress root rots caused by *Phytophthora cinnamomi* for which effective resistant varieties or chemical control procedures other than methyl bromide were not available. The nursery industry discovered that the same composts could also control this disease in field soil. Without compost, Phytophthora root rot was particularly severe in heavy soils and in peat-based potting mixes where up to 90% of the crop of some plant species was killed. The disease also caused severe problems on soils amended with fresh sawdust (Figure 1). Thus, it was recognized early that not all sources of organic matter were effective for disease control.

During the 1970's, plant pathologists performed the first controlled experiments in the US and Australia that confirmed growers' experiences with composts in container media as well as in field soils. Phytophthora collar rot of apple in potting mixes (Figure 2) and Phytophthora root rot of avocado and azalea were early field soil examples. The composts could be applied as mulches or incorporated into the surface soil layer. Figure 3 shows the release of zoospores (fungal resting stage) by *Phytophthora cinnamomi* in a peat mix (Figure 3A) versus the contrasting destruction of sporangia (also a resting stage of the pathogen) by compost (Figure 3B). It was realized that not all pathogens are killed by composts. Sometimes the pathogen is merely suppressed in activity by microorganisms in compost-amended soils.

Since the early 1990's, animal manures have reclaimed their value with farmers for a variety of reasons. Livestock farmers need to manage nutrients in manure more carefully to minimize off-farm environmental contamination. Organic farmers use animal manures as sources of macro and micro nutrients and to build soil organic matter. Livestock farmers have begun to add value to raw manures through composting. The early work on Phymatotrichum root rot of cotton has been repeated with composted manures across the globe in hundreds of tests for numerous crops and for many soil-borne diseases. In general, these studies show that the severity of diseases caused by essentially all types of soil-borne plant pathogens can be reduced by composted manures. However, diseases also can be more severe after compost application if immature compost is used or if the timing of compost application is out of tune with crop needs. Several factors must be addressed to obtain control consistently.

In addition to control of soil borne or below ground plant diseases, research studies conducted in the early to mid 1990's have demonstrated compost-mediated control of foliar diseases. In 1991 it was shown that specific microorganisms in the rhizosphere of plants (the interface between plants roots and surrounding soil) can reduce the severity of diseases on the entire plant. In a 1992 study from Germany, composted cow manure applied to small grains and grapes suppressed powdery and downy mildew, respectively. Other reports from Florida and Ohio showed that application of composted municipal waste and of composted yard wastes to field soil reduced the severity of bacterial spot and of early blight of tomato. Several foliar diseases of beans and cucumber were reduced by incorporating composted paper mill residuals into a sandy Wisconsin soil. Peat and fresh paper mill residuals did not suppress these diseases. It is now known that even *Phytophthora infestans*, the causal agent of late blight of potato, can be affected by systemic resistance induced by composts, also known as *induced systemic resistance* or ISR.

General Concepts Related to Compost-Mediated Disease Suppression

Compost-mediated disease suppression falls into two major categories: general and specific. General suppression results from the collective microbial activity in the growing medium (for example compost amended potting mixes or field soils). The total active pool of microbes in the growing medium competes with plant pathogens for carbon, energy and nutrients like nitrogen. No single organism alone is responsible for general suppression. In contrast, specific suppression occurs through the activities of one or several specific populations of organisms. Scientists believe that select groups of micro-organisms are antagonistic to specific plant pathogens during some phase of the pathogen's life cycle. Specific suppression is more difficult to achieve than general suppression. In most cases, these specific beneficial micro-organisms operate in an environment that is favorable for general suppression as well.

In most cases, there is no single mechanism controlling plant diseases in any given plant growing system; rather several mechanisms operate concurrently to suppress plant diseases. A recent literature review on biologically and organic matter mediated disease suppression highlights several predominant mechanisms (Stone et al., 2004):

1. *Competition for energy and nutrient sources and for organic matter substrate colonization*—When microbial spores (resting stage) are stressed due to insufficient energy or nutrient sources they are less likely to germinate and colonize newly added organic matter. In many cases, pathogenic microbes (either bacterial or fungal) are poor competitors relative to beneficial organisms present in the growing medium. If residues are pre-inoculated with beneficial organisms or if those organisms are already present in the growing medium (e.g.; from compost amended soils or growing media), then pathogenic organisms are less likely to colonize the fresh organic matter.

2. *Antagonism*—Beneficial micro-organisms can destroy pathogenic micro-organism cells (*lysis* is the technical term); they can also produce antibiotics or other substances that are toxic to the pathogenic organisms. For example, *Pseudomonas* spp. have been shown to produce an antibiotic substance that suppresses wheat take-all disease, *Fusarium* wilt of pea, cyst nematode and soft rot of potato, and *Thielaviopsis* root rot of tobacco (Stone et al., 2004).

3. *Competition for root colonization*--In situations where pathogens attack plant roots, some beneficial organisms are better able to colonize the plant roots before the pathogens can get a foot hold. An example of this would be potato root colonization by the nonpathogenic fungal species *Fusarium equiseti* which was positively related to suppression of *Verticillium* wilt (Stone et al., 2004).

4. *Induced systemic resistance (ISR) or systemic acquired resistance (SAR)*--Plants can be stimulated to turn on genes that defend them against attack by pathogens. ISR can provide protection against viral, fungal, and bacterial plant pathogens and root, vascular, and foliar diseases of plants. Microbes inhabiting the micro-environment around plant roots or microbial by-products or organic matter decomposition by-products have been reported to turn on ISR genes in plants.

Factors that affect disease suppression with composts

The degree of disease suppression experienced when soils are amended with organic amendments can vary greatly. Furthermore, organic amendments suppress diseases for a limited period of time. The duration of suppressiveness and degree of efficacy depend on a number of compost and soil factors including:

- Feedstocks from which the compost is prepared
- The composting process
- Salinity of the compost
- Compost maturity
- Microorganisms that colonize composts after peak heating or before planting in soil
- Nutrient content of the compost
- Rate and timing of compost application
- Character of the soil organic matter

The extensive planning required to implement strategies to maximize compost-induced disease suppression includes taking into account interactions among organic amendments, soils and crops. Each of the factors will be reviewed here. Examples of disease control on several crops are used to illustrate reasons for success and failure in disease control.

Feedstocks and Compost Characteristics

The length of time of the suppressive effect depends on the feedstocks from which the compost is made. Tree bark and other woody materials consist mostly of lignin, cellulose, tannins and waxes. These materials resist decomposition. After composting, the disease suppressive effects last for several years in soil, depending on how much was added to the soil. These composts release nutrients (N,P,K, etc.) very slowly at rates similar to forest litter and produce humic acids (large molecular weight organic acids that are very complex and difficult to degrade), which decrease soil pH and act as chelating agents (chemical binding of micronutrients and organic compounds known to aid in disease suppression).

In contrast, food and feed wastes, animal manures and biosolids mostly consist of readily decomposable compounds and nutrients. Smaller molecular weight organic acids known as fulvic acids are produced during composting from these feedstocks and continue to be produced when these composts are applied to the soil. Fulvic acids, like humic acids, chelate essential micro nutrients and keep them available for uptake by plants, even at high soil pH. Chelates can strongly mediate the severity of diseases caused by soil borne plant pathogens. However, these beneficial effects usually do not last more than one or two years in soils. Often, the effect disappears in one year or less in high temperature regions.

The Composting Process

In addition to the feedstocks, the composting process influences the characteristics of the compost and its disease suppression attributes. The methods of composting and the operations that refine the compost can affect the product’s particle size, maturity, nutrient content, salinity and microbial composition. In particular, the compost’s disease suppression attributes depend on the heat generated, and the high temperatures maintained during the composting process. Many composting feedstocks carry organisms that are pathogenic to plants. Fortunately, most plant pathogens are destroyed at the high temperatures that are typical of composting. Therefore, properly prepared compost not only delivers the potential to suppress plant pathogens in the soil, it also delivers few to no pathogens to the plant environment. A high degree of maturity plus hygienic handling and storage of the finish compost ensures that plant pathogens do not recolonize the compost from the surrounding environment.

Compost Salinity

Many plants are stressed by excessively high concentrations of salts (> 10 dS m^{-1} in a saturated media extract) in the root environment. In turn, stressed plants are more susceptible to diseases, particularly root diseases like *Pythium* and *Phytophthora.* Even when the salinity levels are not toxic to the plants, elevated concentrations of salts can negate the disease suppression benefits supplied by the organic and biological components of the compost. Livestock and poultry manure composts tend to have relatively high levels of salts and may not produce the expected disease benefits in container grown plants.

If possible, feedstocks recipes can be adjusted to lower the compost salinity level, although this is often impractical. Alternatively, composts with high salinity can be blended with soil or low-salinity compost (e.g. most yard trimmings composts). For field applications, compost can be applied well ahead of the planting season to allow salts to be leached below the root zone. For mulches, the best approach is to blend composted materials high salinity with woody or bark mulches to dilute the negative factors and provide long-lasting beneficial effects for value added markets. These blends can be applied as mulches at any time of year and provide beneficial effects more consistently.

Compost Maturity

Fresh organic residues, and even immature composts, often have negative effects on plant health for some time after their application to soils and can increase disease incidence and severity. For example, fresh straw applied in the fall as mulch under apple trees or red raspberry bushes increases water retention in soil and immobilizes nitrogen if it has not decayed adequately. As a result, Phytophthora collar rot is aggravated when trees break dormancy and *Phytophthora* becomes active in the spring. Fresh ground wood has similar negative effects in the landscape, but the effect lasts much longer because wood breaks down much more slowly than straw. In contrast, composted wood, which is more like forest litter, suppresses the disease. Examples of diseases that have been aggravated by shredded raw wood mulches and controlled by composts include those caused by *Pythium, Phytophthora, and Rhizoctona,* among others. This principle applies to many crops!

A second problem associated with fresh residues is that they stimulate growth of some plant pathogens that infect roots and cause disease. For example, the pathogens *Rhizoctonia solani* (causes damping-off on almost all crops) and *Armillaria mellea* (can kill mature trees; oaks, kiwi, etc.) can grow on fresh straw and wood. These fungi cannot grow on partially decayed or composted products. *Pythium,* like *Phytophthora*, causes root rot on many plants, particularly in wet soils, and is stimulated by fresh green manures. Green manures need to decompose for 10-14 days after they have been plowed into the soil prior to crop planting to prevent a drastic increase in Pythium damping-off on many crops. Once the green manure is fully colonized by soil microorganisms, the disease is controlled for months thereafter.

For example, a California study showed that lettuce planted in soil one day after vetch was plowed down suffered severe pre-emergence damping-off due to increased *Pythium* activity. One week after plowing the disease was controlled effectively. Thus, farmers who treat green manures with an herbicide to kill the crop and plant a few days later delay beneficial organisms from providing control until this residue has been fully colonized by soil organisms to establish competition, antibiotic production and parasitism. This effect may take weeks for some crops, depending upon soil temperature and moisture content.

In general, fresh residues almost always cause problems unless they decompose to some degree before planting of the next crop. There are strategies to encourage breakdown of crop residues using nutrient rich composts like poultry manure-based composts. For example, application of 2.5-5 mT/HA of poultry manure compost immediately after the harvest of corn speeds up the decomposition of corn stover in the field. The added nitrogen combined with minimum tillage decreases survival of plant pathogens. Thus, seed rot caused by *Pythium* and seed, stalk and ear rot of corn caused by *Fusarium graminearum* can be reduced in severity. The ear rot pathogen produces mycotoxins which have serious detrimental effects on livestock.

At the other end of the spectrum, composts that are very stable or fully decomposed after months or years of decomposition in soil no longer have the ability to support populations of beneficial organisms. As beneficial organism populations decline, plant pathogens increase in number and activity and disease increases in severity. For this reason highly stabilized organic matter, such as peat or geologically old soil organic matter (as found in soils derived from prairies), are not effective in controlling plant pathogens unless new sources of stable organic matter are added.

Compost Microorganisms

The types of diseases that are suppressed by composts depend very much on the types of microorganisms that colonize the material, especially for specific disease suppression mechanisms. Many years of scientific and field observations have revealed that root rots from soil-borne plant pathogens such as *Phytopthora* and *Pythium* are readily controlled by many different types of microorganisms. These diseases are likely to be suppressed consistently by compost amendments if the compost is mature and low in salinity. Other diseases, such as those caused by *Rhizoctonia solani* (damping -off on most plants in seedling stage) and *Fusarium* (causes wilt) and *Sclerotium rolfsii* (southern blight), require more specialized biocontrol agents. When used in potting mixes, only 20% of more than 300 types of composts tested provided natural control of Rhizoctonia damping-off, whereas suppression of Pythium diseases was essentially consistent. It is not surprising, therefore, that several reports show that composts do not consistently suppress Rhizoctonia damping-off in the field even when Phytophthora and Pythium root rots are suppressed. In fact, composts can increase Rhizoctonia diseases in field soil because the pathogen is more aggressive in porous (like compost-.amended) soils, especially if biocontrol agents are not present to kill it out right at planting.

Antagonistic organisms, intentionally added to the growing medium, are effective only when operating against a background of general disease suppression. Suppression can also be lost as the organic amendment or residue decomposes and the substrates that support the activity of specific antagonists are depleted. Therefore, successful inhibition of *Rhizoctonia solani* in soil less media relies on maintaining environmental conditions that support (1) general suppression, (2) colonization by specific antagonists, and (3) the activity of specific antagonists.

In some instances, it takes weeks or even months for specific biocontrol agents to colonize the compost naturally. One solution to this problem is to apply mature composts 4-6 weeks before planting to allow beneficial microorganisms to colonize the compost amended soil (their food base) and set the stage for disease control. Indeed, this approach is effective if the compost applied is mature and low in salinity. A second solution is to inoculate compost with specific biocontrol agents. Commercial preparations of *Bacillus, Trichoderma* or other species are still under development. They need to be applied when the compost is utilized so they have a chance to colonize the food base before other low temperature microorganisms out compete them. Excellent control of Rhizoctonia damping-off and of Fusarium wilt diseases has been obtained at commercial levels since 1996 with composts inoculated with these specific biocontrol agents.

Strains of *Bacillus* and of several *Trichoderma* species that induce systemic resistance in plants to disease are available commercially. Several of these microorganisms also promote plant growth. They are more effective in compost-amended than in peat-based growing media. Tests in potting mixes with one such strain, *Trichoderma hamatum* 382 (T382), show that Botrytis blight and powdery mildew of begonia, bacterial blights of several vegetable crops in addition to Phytophthora leaf blight of cucumber and of several different woody ornamentals can be reduced in severity by composts inoculated by this biocontrol agent (Figure 6). A stress canker disease caused by *Botryospaeria dothidea* on *Myrica pennsylvanica* also can be controlled by this organism. Effective fungicides are not available for this stress disease that affects many woody plants and orchard trees. It was also found, unfortunately, that plants which lack resistance entirely (extremely susceptible cultivars) do not respond to treatment with this biocontrol agent. Thus, this field still is in a developmental stage.

Compost Nutrient Content

A growing body of research has demonstrated a link between soil fertility and plant disease incidence/severity. In general if plants are either nutrient stressed (limited) or their roots are surrounded by a nutrient surplus, they are more susceptible to disease. Nitrogen (N) is the primary nutrient to consider and mineral forms of N specifically (ammonium and nitrate), as N availability from composts or mulches varies more than that of any other nutrient, and mineral N availability has a major effect on plant disease. Bacterial leaf spots, fire blight and Fusarium wilts are examples of diseases aggravated by high doses of nitrogen-rich composts. Composted biosolids, cow and swine manures typically contain 1.7-2.5% total nitrogen (dry wt.). Typically, 10-30% of the total nitrogen in these composts is converted to mineral N forms (ammonium and nitrate) within the first three months after their amendment to soil. The remainder may be released in as little as two to three years or as long as 30 years or more. In general, composts with high nitrate concentrations or composts that mineralize high concentrations of nitrate during the growing season may exacerbate certain plant diseases.

A lack of available N can also aggravate plant disease incidence/severity, especially in the case of fresh organic matter or immature compost. Composts that are relatively young with a high degree of biological activity can tie up or immobilize N when applied to the soil. Since N release or mineralization from these composts is dependent on soil microbes, they may create a temporary N deficiency for plants and favorable conditions for plant pathogens to take hold.

Compost Application Rates and Timing

Compost analysis, soil test results, and crop need together should form the basis for determining compost application rates. In the field, release of nutrients by composts, particularly that of N must be balanced against what is in the soil and the requirements of the crop. After farmers have applied compost to soil, it becomes more important to properly evaluate the quantity of nutrients released from the organic matter in the soil before any additional material is applied. Fruit growers who do not address this issue will increase fire blight on apple due to excessive N fertility even though they will maintain control of Phytopthora collar rot. Grape producers would decrease wine quality. This was observed as the only possible negative aspect associated with 30 years of compost use in Italian vineyards when soil fertility was not addressed adequately.

High application rates (2-3 inches incorporated into the top 6-8 inches of soil)of low N composts (e.g. bark or leaf derived composts with an N content lower than 1.7%) have been used to control soil borne diseases in ornamental nursery crops. This approach has eliminated the need for methyl bromide fumigation in these crops since the 1970's. Moderate to high application rates of composts can replace methyl bromide for control of the strawberry black root rot complex which is caused by several pathogens (Figure 4).

For products with relatively high N content (e.g. composted biosolids or manure), an inch of compost tilled into the top 10 cm (4 inches) of soil prepares an ideal seed bed for most woody plants and for seeding new lawns. Crops sensitive to ammonium N and Fusarium wilt should be treated with highly stabilized composts only so that much of the free nitrogen in the compost is present as nitrate-nitrogen. Especially on sandy soils, care must be taken to avoid ammonium toxicity. The best approach is to apply these materials several weeks before planting so that much of the ammonium is converted to nitrate. On crops highly susceptible to Phytophthora root rots and salinity such as soy beans, composts, should be applied months ahead of planting, particularly those prepared from manures. In regions where crops are planted immediately after another has been harvested, it would be best to apply compost to a crop produced before the susceptible crop.

High salt composts (composted manures, biosolids) and fresh materials that have not been composted should be applied in the fall or winter when pathogens and the crop are least active. This approach allows time for leaching of salts and for decomposition and establishment of beneficial effects. Composts that are high in salinity increase *Phytophthora* and *Pythium* disease pressures rather than provide control if applied in the spring or summer when these pathogens are most active. Fall application avoids the issue on a crop such as soybean which is highly susceptible to the disease. Corn is resistant to *Phytopthora* and can be amended with these composts before planting.

Character of the Soil Organic Matter

Organic matter acquires beneficial characteristics soon after it begins to decay. Beneficial microorganisms thrive on this decaying material. The particle size, particle density and age (degree of decomposition) of soil organic matter seem to set limits on disease suppression. The largest, least decomposed particles of organic matter do not seem to contribute directly to disease control, but as they decrease in particle size through decomposition, their effectiveness increases. Several reports also suggest that the finest, most stabile fraction also does not contribute to long term biological control. This fraction, as mentioned above, is so biologically stabile that it cannot support beneficial microorganism populations. Soil scientists use organic matter particle size and density to characterize the degree of biological activity of different organic matter fractions or pools. In general, the fraction of soil organic matter identified as particulate organic matter or POM seems to be most closely related to disease suppressiveness. This fraction is isolated from soils by dispersing them in water and then collecting the soil and organic matter that accumulates on a sieve with mesh size of 53 microns. Of course, there are some exceptions. For example, pyrolized bark particles, which essentially are inert, will not support disease control. In contrast fine particles (smaller than 53 microns) from certain composts may support disease control but only for a short period of time (3-6 months).

In addition to linking disease suppression to specific organic matter fractions, scientists have found strong correlations between disease suppression and microbial activity. The rate of hydrolysis of fluorescein diacetate (FDA activity) is a relatively simple and rapid technique employed to measure soil microbial activity. This FDA microbial activity seems to best predict the potential for biocontrol of root rots and the longevity of this effect in soil. This applies to compost-amended potting media as well as field soils. The concentration of microbial biomass also can be indicative, especially when combined with FDA activity, based on research in potting mixes in Ohio and several years of research thereafter in compost-amended versus control field plots under fruit trees in Nedlands, Australia and on organic vegetable farms in Witzenhausen, Germany. This entire field is being studied by soil scientists in several locations across the world. Guidelines for interpretation of data obtained from these soil tests are being developed.

There are also interactions between organic matter decomposition level and soil physical conditions, and those interactions also affect disease incidence and severity in some crops. The structure of the soil is improved by partially decomposed organic matter. This transformation results in better water retention under dry weather conditions and improved drainage during periods of high precipitation. The improved soil condition, in turn, leads to natural root rot suppression in wet soils and some degree of suppression of wilt diseases in dry soils. Examples are Phytophthora root rot, which is prominent in wet soils, and the early dying disease of potato, caused by a complex involving nematodes and *Verticillium* in dry soils.

Conclusions

Composts applied to soils can provide biological control of root as well as foliar diseases of plants. The compost must be of high quality. It must be prepared by a consistent process and from known raw materials. The compost must be applied at a time of year and application rate that meets the fertility needs of the crop. Soil fertility must be included in these decisions. Fall application is required for crops sensitive to Phytopthora root rot if composts high in salinity are used. Crops such as small grains are much less sensitive to these diseases but they may suffer from Rhizoctonia damping-off. For these crops also, it is better to apply the compost a month or more ahead of planting to minimize this problem. It also avoids ammonium toxicity induced by slightly immature composted manures that still are high in ammonium content.

Biocontrol agents may need to be inoculated into the compost while it is applied to obtain consistent effects against some diseases. After several years of compost applications, the diversity of beneficial microorganisms in soil increases and the need for utilization of specific inoculants should decrease. The quantity of nutrients in the soil eventually accumulates also in soil and this must be considered in subsequent application rates to avoid increasing the severity of disease due to excessive nutrient concentrations. In conclusion, many factors must be considered to obtain positive and consistent disease suppressive effects with composts.

Suggested Readings

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