Soil Organic Matter Quality and Induced Resistance of Plants to Root Rots and Foliar Diseases

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INTRODUCTION

Nurserymen and landscapers have recognized for centuries that composts can improve plant health. Many factors must be controlled, however, to obtain consistent effects. The degree to which the raw material is heated during composting affects the potential for killing pathogens and weed seeds. The degree to which the organic matter has been stabilized plays a role in disease suppression and plant growth. Furthermore, composts do not always become colonized naturally by beneficial microorganisms and this can lead to failures. Finally, the concentration of salts and the quantity of nitrogen released by composts plays a role in disease suppression. These factors are briefly reviewed here. We also provide some general information on composts widely available to the nursery industry and how best to use such products.

Most beneficial effects induced by composts are due to the activities of microorganisms in the rhizosphere, the area of soil immediately surrounding the roots. Soil organic matter (composts) has a major effect on the types of microorganisms present in the rhizosphere. Some of these microorganisms produce plant growth hormones and stimulate plant growth directly. Others produce natural chelators called *siderophores* that keep iron at a high concentration in available form to plants in soil, even at pH 7.6. Composts also produce water-soluble humic substances, including fulvic acids, which keep iron, zinc, manganese, and other trace elements in solution. This probably explains why growers using composted biosolids can produce "acid-loving" plants such as azaleas at pH 7.4 in container media consisting of aged pine bark (60%), fibrous sphagnum peat or composted rice hulls (20%), composted biosolids (10% to 15%), and silica sand, in regions where the irrigation water is high in carbonates. It is very difficult to grow azaleas in peat mixes in areas with high carbonate water, because trace elements limit growth as the pH of the peat mix increases and their solubility decreases. Peat mixes are too decomposed to support these beneficial effects.

Beneficial microorganisms that control diseases are known as biocontrol agents. Disease control obtained with this microflora is attributed to four mechanisms. The first is competition for seed, root, or leaf exudates (sugars, etc.) that leak out of seeds during germination or root tips as plants grow through the soil. Pathogens swimming to these sources of nutrients must compete with this beneficial microflora in the infection court. This reduces infections and therefore disease. Some biocontrol agents produce antibiotics effective against pathogens. Yet another group parasitizes pathogens. Microarthropods such as springtails and mites actually search out pathogen propagules in soils and devour them. The fourth mechanism involves the induction of systemic resistance in plants by microorganisms present in composts. A few beneficial microorganisms can induce all four mechanisms.

Our group has shown recently that some microorganisms colonizing roots in compost mixes activate biochemical pathways in plants leading to resistance to root as well as foliar diseases. This mechanism explains the often heard statement that plants on "healthy organic soils" are more able to resist disease. It has now been proven that compost can indeed support such effects. Details of our work are described below.

Most of the sphagnum peat sold for use in container media is of a decomposition level that cannot support the growth and activity of beneficial microorganisms. We have determined that such peat mixes are conducive (no suppression) to all diseases tested. In Figure 1 we show plants produced with one half of their roots in one mix and the other half in a second. The plant in the center had both sides in a sphagnum peat mix (H_4 on the von Post decomposition scale). The right side was in a mix infested with *Pythium*, a root rot and damping-off pathogen. Note that the roots of the center plant with both sides in the peat mix were small relative to the others. The rest rotted. The plant on the right had both sides in a composted pine bark mix with *Pythium* on the right side. Note the healthy root system. The plant on the left shows the systemic effect. The right side was in peat, also with *Pythium*, but the left

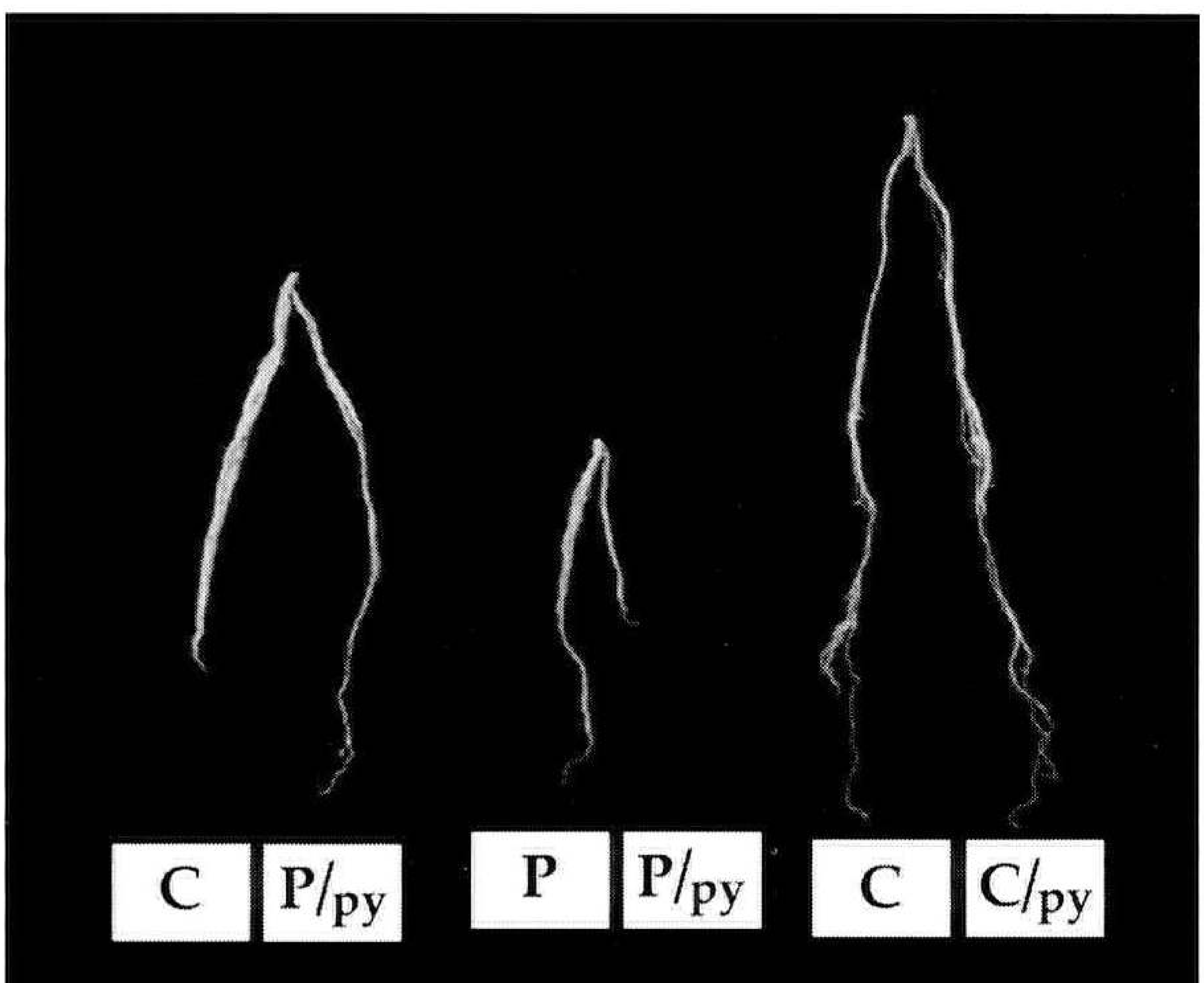

Figure 1. Roots of cucumber plants were transplanted into split-root pots containing a suppressive compost mix (C) or a peat mix (P) conducive to the disease in each half of the pot. The mix in the right half of each pot was infested with the pathogen *Pythium ultimum* (py). Note induced suppression by the compost mix.

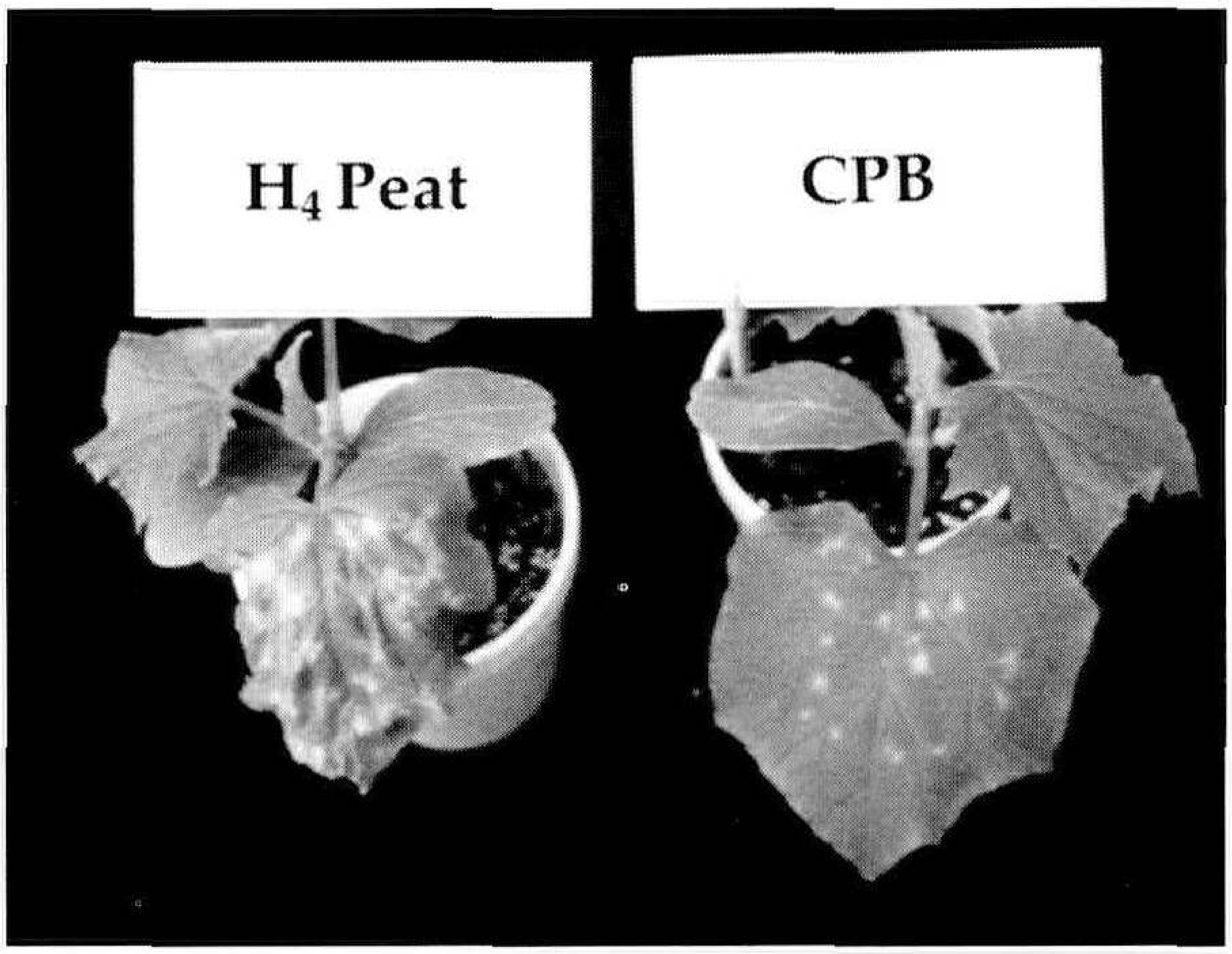

Figure 2. Cucumber plants with anthracnose were grown in pots containing a peat mix (H_4) or a compost mix (CPB). Note the reduced disease severity on the plant grown in the compost mix.

in the compost mix. When the compost was sterilized, it did not control the disease. Somehow, the microflora in the compost seemed to induce factors in the roots on the left that transferred to roots on the right in the peat mix which made the plant resistant to root rot.

In Figure 2, we show an example of control of a fungal disease of cucumber (anthracnose) on the foliage of a plant produced in a composted pine bark mix. The plant on the left, where the disease was much more severe, was grown in an H_4 peat mix. Some bacterial diseases in the foliage of plants can also be controlled in this way with several types of composts in the mix. Sterilized composts do not cause these effects until after they have become colonized by this flora again. This is an important finding because good control procedures for diseases such as fireblight, bacterial blight of lilac, *Xanthomonas* leaf spot on ivy, etc., are not available.

We have now identified some of the microorganisms in composts that can induce this systemic effect. Plants produced in any of several compost-amended mixes tested so far have higher concentrations of an enzyme related to host defense mechanisms. Plants grown in the peat mix that does not provide biological control do not have this elevated level of enzyme activity. In summary, our work shows that plants grown in substrates rich in biodegradable organic matter support microorganisms that induce systemic resistance in plants. These plants have elevated levels of biochemical activity relative to disease control and are better prepared to defend themselves against diseases.

It is important to realize that composts usually do not provide total disease control. When all conditions are favorable, composts offer the potential to reduce many diseases to below critical threshold levels. *Pythium* and *Phytophthora* root rots are among the most easily controlled diseases. Some foliar diseases such as *Phytophthora* die-backs typically are not controlled at all, particularly when high fertility levels are maintained in the crop.

SELF-HEATING KILLS PATHOGENS BUT, UNFORTUNATELY, ALSO MOST BENEFICIAL MICROORGANISMS

Some landscapers utilize fresh wood chips as mulch. The question is, can this lead to spread of diseases? The answer is yes and such mulches also increase the activity of pathogens already on the site!

C. Ash, formerly at the University of Minnesota, has shown that fresh mulch prepared from maple trees that died from *Verticillium* wilt killed tomatoes mulched with this material. *Verticillium* was recovered from the dead tomato plants. This study demonstrated that pathogens in freshly ground infected trees can indeed cause problems in the landscape. Damping-off of bedding plants has been observed in Ohio landscapes mulched with fresh woody materials. Avocado trees mulched with fresh crop debris also suffer more from *Phytophthora* root rot. *Rhizoctonia* damping-off also occurs in bark mixes used during propagation even though Phytophthora root rot is controlled. How can these problems be avoided?

First of all, pathogens, insect egg masses, weed seeds, etc., are killed when temperatures in compost piles exceed 130F for just a few days. Turning of piles so that all parts are exposed to high temperature ensures that pathogen destruction occurs. Those that are not killed outright are weakened and more susceptible to parasitism. Many technical articles support this statement.

It is important to stabilize organic matter in mulches. Organic matter must be stable enough so that plant pathogens cannot utilize it directly as a food base. Otherwise, the mulch actually increases the population of the pathogen. *Rhizoctonia* is an example of a plant pathogen that can grow on fresh mulches. Another reason for partial composting of mulches is that some beneficial microorganisms grow strictly as saprophytes (as on dead organic material) in fresh mulches. Once the mulch is partially decomposed, these beneficial microorganisms must now compete for nutrients. They now produce several types of competitive products that lead to pathogen kill or inhibition. This does not occur in fresh wastes. Some *Trichoderma* isolates serve as examples of a group of beneficial microorganisms that behave in this manner. In conclusion, application of fresh residues to crops or trees should be avoided when the crop is susceptible to disease. Fall or winter application avoids this problem.

What is the best method to compost fresh wood chip mulches to reach these beneficial effects? After just a few weeks of composting, the organic matter in most materials is already stabilized enough for most diseases to be controlled. The best way to accomplish this quickly with fresh ground brush is to enrich it with nitrogen. Add 1 lb urea per cubic yard, or grass clippings (10% to 20% by volume), composted sewage sludge (10% to 15% by volume), composted poultry manure (10 to 20 lb $yard^{-3}$), or another source of nitrogen to decrease the carbon to nitrogen ratio to within the optimum range for composting. Be certain to add water to the pile to maintain a moisture content of 50% to 60% on a total weight basis because ammonium volatilizes as gaseous ammonia out of the pile when it is too dry. The best procedure is to compost woody materials for 6 weeks before they are used as a mulch. The mulch should no longer give off ammonia odors then and begin to smell like soil.

The procedures proposed above kill pathogens and adequately stabilize most materials for use as mulches. Depending on the material being composted, it may have to stabilize much longer before it is suitable for soil incorporation as compost to avoid nitrogen immobilization.

COLONIZATION OF COMPOSTS AFTER PEAK HEATING BY BENEFICIAL MICROORGANISMS

Very few beneficial microorganisms can survive in the high temperature part of compost piles. Most survive in the outer low temperature layer where they constantly reestablish their populations after turning of windrows if several factors are addressed. First, the moisture content must be above 35% in the organic matter fraction of composts for beneficial microorganisms to colonize the substrate. They actually grow as biofilms on the surface of organic matter, particularly if the moisture content is maintained above 45%. Dusty, dry composts and mulches become colonized by molds that cause a variety of problems. These problems can range from difficulties in wetting of the compost-amended soil or mix because fungal masses repel water, to inhibition of plant growth due to deleterious-to-growth microorganisms (minor fungal pathogens). Some fungi cause problems as toadstools in dry mulches or potting mixes.

Allowing composts to cure while a moisture content of 45% to 55% is maintained reduces the potential for all of these problems. Plant growth-promoting bacteria and bacterial biocontrol agents naturally colonize such higher moisture content mulches and compost after peak heating because a thin layer (film) of water surrounds organic matter particles at this moisture content. Bacteria cannot readily colonize dry surfaces, whereas fungi thrive as long as the moisture content ranges from 15% to 34%.

When all factors are optimized, 20% of the compost batches tested still are somewhat deficient in natural biological control when the moisture content of the compost is kept above 40% on a total weight basis. To maximize disease control, composts must be inoculated with specific biocontrol agents. Commercial inoculants for compost consistently providing these beneficial effects are now being registered with the US-EPA. Mixtures of cultures are better than single strains, and broad spectrum control of soilborne as well as some foliar diseases should soon become possible in practice.

HOW LONG DO DISEASE SUPPRESSIVE EFFECTS LAST?

The readily biodegradable fraction of the organic matter in composts and soils sustains the activity of biocontrol agents. Humic substances do not support this activity; they are too resistant to decomposition to support such activity. The population of beneficial microorganisms steadily declines as decomposition proceeds. Each material has its own properties in this regard. We have characterized these trends for sphagnum peat and cow manure. The concentrations and composition of lignocellulosic substances (lignins and celluloses; not the humic acids) determine this effect. Once these materials are decomposed, the beneficial microorganisms decline in activity, the pathogen population recovers and fungicides must be applied for sensitive crops to remain disease free.

For light sphagnum peat (H_2 to H_3 on the von Post decomposition scale), the beneficial effect lasts 6 to 12 weeks in greenhouse crops. In outdoor containers in hot weather, the length of time may be reduced 50% because of the higher temperature. Pine bark can support this effect 6 months to 1 year. However, pine bark aged in large piles where pyrolysis or fires occur behaves more like charcoal and offers little disease control potential, even though it still may have ideal physical properties for use in container media to control root rots. Hardwood bark incorporated at 15% by volume lasts two seasons in Ohio. Composted sewage sludges last through 2 years (at 10% to 15% by volume in a mix). Composted rice hulls and coconut coir (husks) also have an effect, but the length of time that the suppressive effects last has yet to be determined. Composted paper mill sludges can also be used for long-term beneficial effects.

Some knowledge is available from field studies also. In general, the same material should last longer in the field because soil temperatures are lower than those in containers. The best results are obtained in the field if the compost is applied as a mulch on the soil surface. Only a small fraction (5 to 10 dry tons acre^{-1}) of the compost should be incorporated into the soil. The remainder (25 to 50 dry tons acre^{-1}) should be applied on the surface after planting. An exception to this general rule is where compost is applied ahead of a vegetable crop planted for an early harvest. Soil temperatures remain lower in mulched soils and this can set back early vegetable crops. The quantity and form of mineral fertilizers applied needs to be adjusted in succeeding years to avoid overloading with nutrients. In general, fine particulate composts should be incorporated. Coarse particles perform better as mulches.

The following examples illustrate control of diseases with composts in field soils. Composted hardwood bark mulch applied to apple trees at planting controlled *Phytophthora* collar rot through 2 years in a 1978-1981 OSU field study where inoculum of the pathogen was used. A recent study by Dr. Funt from the OSU Department of Horticulture and Crop Science revealed that composted yard waste (50 tons acre^{-1}) on strawberry maintained plant stand beyond 3 years whereas plants in control plots declined. In Western Australia, a composted manure is used to suppress Phytophthora root rot of avocado for well into the 2nd year after mulching. Similar results are being obtained in orchards in Southern California today through the work of Dr. J. Menge at the University of California, Riverside. Much more work needs to be done in this field, however, before general advice can be provided.

EFFECTS OF SALINITY AND FERTILITY IN COMPOSTS ON PLANT DISEASES

An increasing number of compost producers with experience in this field realizes that the composition of raw materials, the composting process as well as curing, screening, etc., must be kept constant to produce consistent quality products. Furthermore, soil analysis laboratories increasingly are capable of predicting the fertility values of composts. Nutrient inputs must be balanced against crop needs and the residuals in the soil.

Composted pine bark and peat, because of their resistance to decomposition, do not release or immobilize significant quantities of nutrients. Therefore, essential micronutrients must be incorporated into the mix. Composted hardwood bark immobilizes N early but releases various nutrients, including trace elements, later. Composted sewage sludges available in Ohio release 25% of the total N in the first few months after utilization. Therefore, adjust the incorporation rate to the fertility needs of the crop. Generally, this means do not use more than 10% to 20% of this compost by volume in a mix, depending upon fertility needs of the crop. Overloading with this nitrogen-rich compost increases fireblight, *Phytophthora* die-backs, and *Fusarium* wilts. All trace elements are supplied adequately by composted sewage sludges, particularly in high pH irrigation water regions. Trace elements do not need to be applied.

Composted leaves also supply trace elements, not much nitrogen, and significant quantities of potash. Composted yard wastes supply some nitrogen if prepared with grass clippings, and may contain up to 1% available potash. All of these composts provide phosphorus, calcium, and magnesium. Most do not have to be amended with lime but addition of sulfur to lower the pH to 5.5 also may not be necessary even though most laboratories recommend it. It makes a lot of sense to blend low nitrogen with high nitrogen composts. Mixtures of composted yard wastes and composted sewage sludges increasingly are preferred in several applications.

Two studies (OSU and Israel) have shown that concentrations of available iron, zinc, and manganese are very high at a soil pH above 7.0 in composted cow manure or sewage-sludge-amended mixes. As mentioned previously, we have determined that plants, including azaleas, grow very well and without trace element deficiencies at pH 7.0 or higher in these mixes because siderophores (natural chelators) and water-soluble humic substances keep them in solution.

All composts can be high in salinity. As composts mature, mineralization proceeds and the concentration of salts increases. Because compost piles often do not leach, salts accumulate with time. Always monitor the conductivity reading of a new batch. Incorporate based on salinity limits, if needed, or apply composts well ahead of planting to allow for leaching. Manure composts now becoming more widely available will have to be monitored most closely for salinity problems. High salinity destroys suppressiveness to *Phytophthora* and *Pythium* root rots. For example, composted sewage sludge was applied to soybeans in Ohio during the early 1980s in an attempt to control *Phytophthora* root rot. The disease was increased in each of 4 years when the compost was applied directly ahead of planting. However, in plots where the compost was applied 3 months prior to planting (February) or in the previous fall, the disease was controlled and the yield increased. The damage done by the compost could be mimicked by an application of salt (NaCl) directly ahead of planting. These factors must be considered carefully in biological control of plant diseases.

The foregoing is a brief synopsis of some of the knowledge available today of compost utilization relative to maintenance of plant health.

REFERENCES SUGGESTED FOR FURTHER READING

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