Figure 30

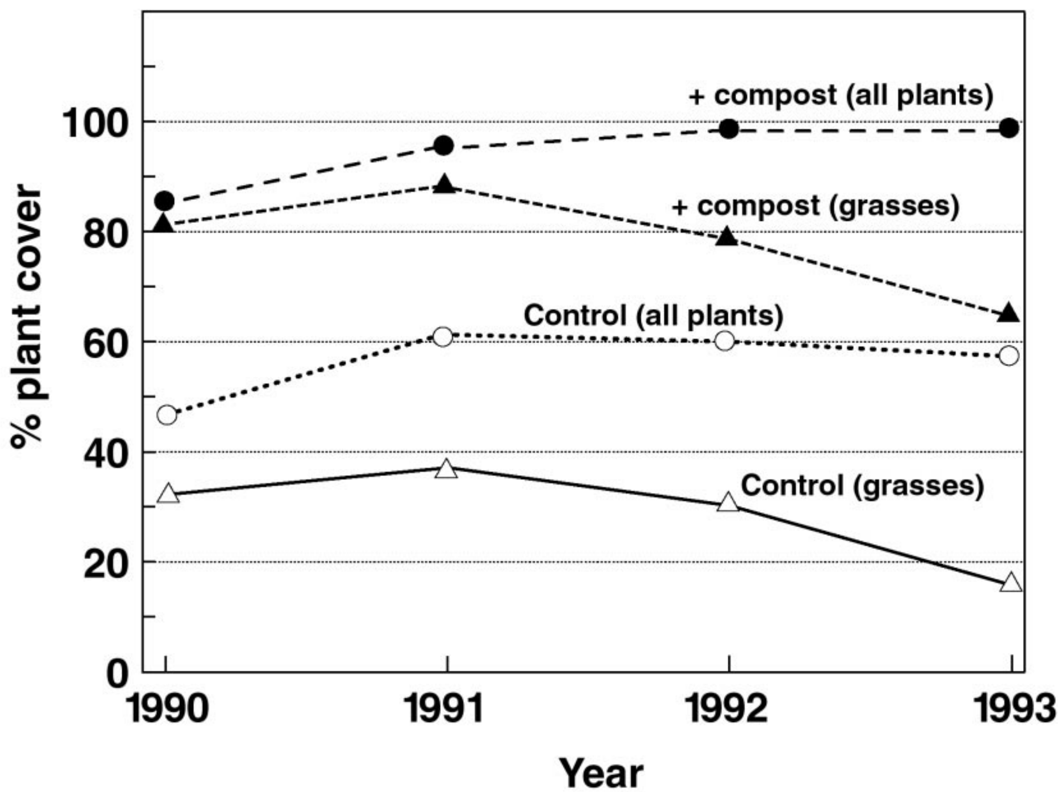
Plant Establishment With or Without Compost Addition

Revegetation occurred only in plots to which compost was added.

Source: Atkinson, 1992

Figure 31

Enhanced Revegetation of Ski Tracks by Addition of 125 Tons of Compost Per Hectare



References

Airst, R.L. "Turning Brownfields to Greenbacks." *Environmental Protection* (November 1996): 28-29, 35.

Almendros, G., R. Frund, F.J. Gonzalez-Vila, K.M. Haider, H. Knicker, and H.D. Ludemann. "Analysis of ^{13}C and ^{15}N CPMAS NMR-spectra of Soil Organic Matter and Composts." *FEBS Letters* 282 (1991): 119-121.

Atkinson, S.L., J.M. Lopez-Real, and G.P. Buckley. "Evaluation of Composted Sewage Sludge-straw for the Reclamation of Derelict Land: The Reclamation of Colliery Spoil." *Acta Horticulturae* 302 (1992): 237-248.

Avnimelech, Y., M. Kochva, Y. Yotal, and D. Shkedy. "The Use of Compost as a Soil Amendment." *Acta Horticulturae* 302 (1992): 217-236.

Bolton Jr., H. and Y.A. Gorby. "An Overview of the Bioremediation of Inorganic Contaminants." In *Bioremediation of Inorganics*, edited by R.E. Hinchee, J.L. Means, and D.R. Burris, 1-16. Columbus, OH: Battelle Press, 1995.

Carey, J. "Urban Fields of Dreams." *Business Week* (May 1996): 80-86.

Chaney, R.L. and J.A. Ryan. *Risk Based Standards for Arsenic, Lead, and Cadmium on Urban Soils*. Frankfurt, Germany: DECHEMA, 1994.

Cichon, E. "Changing the Focus of Brownfields Cleanups." *Pollution Engineering* 29 (April 1997): 48-50.

Ettlin, L., and B. Stewart. "Yard Debris Compost for Erosion Control." *BioCycle* 34 (December 1993): 46-47.

Fenton, G.K. "Temporal Variation of Soil Hydraulic Properties on Municipal Solid Waste Amended Mine Soils." *Transactions of the American Society of Agricultural Engineers* 38 (1955): 775-782.

Fitzgerald, P.R. "Recovery and Utilization of Strip-mined Land by Application of Anaerobically Digested Sludge and Livestock Grazing." In *Utilization of Municipal Sewage Effluent and Sludge on Forest and Disturbed Land*, edited by W.E. Sopper and S.N. Kerr, 498-506. University Park, PA: The Pennsylvania State University Press, 1979.

Gaffney, G.R. and R. Ellertson. "Ion Uptake of Redwinged Blackbirds Nesting on Sludge-treated Soils." In *Utilization of Municipal Sewage Effluent and Sludge on Forest and Disturbed Land*, edited by W.E. Sopper and S.N. Kerr, 507-515. University Park, PA: The Pennsylvania State University Press, 1979.

García, C., J.L. Moreno, T. Hernández, F. Costa, and A. Polo. . "Effect of Composting on Sewage Sludges Contaminated With Heavy Metals." *Bioresource Technology* 53 (1995): 13-19.

Griebel, G.E., W.H. Armiger, J.F. Parr, D.W. Steck, and J.A. Adam. "Use of Composted Sewage Sludge in Revegetation of Surface-mined Areas." In *Utilization of Sewage Effluent and Sludge on Forest and Disturbed Land,* edited by W.E. Sopper and S.N. Kerr, 293-305. University Park, PA: Pennsylvania State University Press, 1979.

Hinesly, T.D., L.G. Hansen, E.L. Ziegler, and G.L. Barrett. "Effects of Feeding Corn Grain Produced on Sludge-amended Soil to Pheasants and Swine." In *Utilization of Municipal Sewage Effluent and Sludge on Forest and Disturbed Land*, edited by W.E. Sopper and S.N. Kerr, 481-495. University Park, PA: The Pennsylvania State University Press, 1979.

Hoddinott, K.B. (ed.). *Superfund Risk Assessment in Soil Contamination Studies*. Philadelphia, PA: American Society for Testing and Materials, 1992.

Kerr, S.N., W.E. Sopper, and B. R. Edgerton. "Reclaiming Anthracite Refuse Banks With Heat-dried Sewage Sludge." In *Utilization of Sewage Effluent and Sludge on Forest and Disturbed Land*, edited by W.E. Sopper and S.N. Kerr, 333-351. University Park, PA: The Pennsylvania State University Press, 1979.

Ma, O.Y., T.J. Logan, and S.J. Traina. "Effects of NO_3^-, Cl^-, F^-, SO_4^{2-}, and CO_3^{2-} on Pb^{2+} Immobilization by Hydroxyapatite." *Environmental Science and Technology* 28 (1994): 408-418.

National Research Council. *Ranking Hazardous-Wastes Sites for Remedial Action*, 294. Washington, DC: Academy Press, 1994.

Pinamonti, F. and G. Zorzi. "Experiences of Compost Use in Agriculture and in Land Reclamation Projects." In *The Science of Composting*, edited by M. de Bertoldi, P. Bert, and P. Tiziano, 517-527. London: Blackie Academic and Professional, 1996.

Rodale, J.I. "Chapter 9: Advantages of Compost Farming." In *Pay Dirt,* 83-92. New York: The Devin-Adair Company, 1945.

Rupert, D.R. "Use of Spent Mushroom Substrate in Stabilizing Disturbed and Commercial Sites." *Compost Science and Utilization* 3(1) (1995): 80-83.

Russell, E.J. *Soil Conditions and Plant Growth, 10th Edition*, 530. London: Longman Group Limited, 1973.

Ryan, J.A. and R.L. Chaney. "Regulation of Municipal Sewage Sludge Under the Clean Water Act Section 503: A Model for Exposure and Risk Assessment for MSW-compost." In *Science and Engineering of Composting*, by H.A.J. Hoitink and H.M. Keener, 422-450. Worthington, OH: Renaissance Publications, 1993.

Sabrah, R.E.A., H.M.A. Magid, S.I. Abdel-Aal, and R.K. Rabie. "Optimizing Physical Properties of a Sandy Soil for Higher Productivity Using Town Refuse Compost in Saudi Arabia." *Journal of Arid Environments* 29 (1995): 253-262.

Schnitzer, M. and H. Kodama. "Reactions of Minerals With Soil Humic Substances." In *Minerals in the Soil Environment*, 741-770. Madison, WI: Soil Science of America, 1977.

Slutzky, D., and L. Jacobson. "EPA's Brownfields Initiatives." *Mortgage Banking* 55 (July 1995): 91-93.

Smith, L.A. and J.M. Houthoofd. "Considerations in Deciding to Treat Contaminated Soils in Situ." In *Bioremediation of Inorganics*, edited by R.E. Hinchee, J.L. Means, and D.R. Burris, 149-164. Columbus, OH: Battelle Press, 1995.

Stark, L.R., W.R. Wenerick, F.M. Williams, S.E. Stevens, Jr., and P.J. Wuest. "Restoring the Capacity of Spent Mushroom Compost to Treat Coal Mine Drainage by Reducing the Inflow Rate: A Microcosm Experiment." *Water, Air, and Soil Pollution* 75 (1994): 405-420.

Steffen, R. "The Value of Composted Organic Matter in Building Soil Fertility." *Compost Science and Land Utilization* 20 (September/October 1979): 34-37.

Trout, T.J., R.E. Sojka, and R.D. Lentz. "Polyacrylamide Effect on Furrow Erosion and Infiltration." *Transactions of the American Society of Agricultural Engineers* 38 (1995): 761-766.

Tyson, S.C. and M.L. Cabrera. "Nitrogen Mineralization in Soils Amended With Composted and Uncomposted Poultry Litter." *Communications in Soil Science and Plant Analysis* 24 (1993): 2361-2374.

Warman, P.R., T. Muizelaar, and W.C. Termeer. "Bioavailability of As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Se, and Zn From Biosolids Amended Compost." *Compost Science and Utilization* 3(4) (1995): 40-50.

Williams, B.D. and P.E. Packer. "Sewage Sludge and Other Organic Materials as Amendments for Revegetation of Spent Oil Shale." In *Utilization of Municipal Sewage Effluent and Sludge on Forest and Disturbed Land*, 353-358. University Park, PA: Pennsylvania State University Press, 1979.

Xu, Y., F.W. Schwartz, and S.J. Traina. "Sorption of Zn^{2+} and Cd^{2+} on Hydroxyapatite Surfaces." *Environmental Science and Technology* 28 (1994): 1472-1480.

Chapter 5

Suppression of Plant Diseases and Pests by Compost

Plants are susceptible to damage or death as a result of attack on their seeds, stems, leaves, and root systems from a wide range of disease-causing microorganisms, insects, and nematodes (microscopic worms). Farmers and horticulturists suffer billions of dollars in losses as a result of this damage. For the past 40 to 50 years, synthetic pesticides have been used to control these problems. The use of many of these common pesticides—particularly soil fumigants that are effective controls for fungi and nematodes—has been prohibited or severely restricted during the past 20 years (Quarles, 1995). Increasingly stringent standards designed to protect agricultural workers from pesticide exposure also have been developed. These restrictions on pesticide use have sparked substantial interest in using natural biological processes to control pests and pathogens.

Biological control is the use of one biological species to reduce populations of a different species. Successful and commercialized examples include ladybugs to depress aphid populations, parasitic wasps to reduce moth populations, use of the bacterium *Bacillus thuringenensis* to kill mosquito and moth larvae, and introduction of fungi, such as *Trichoderma*, to suppress fungal-caused plant diseases. In all of these cases, the idea is not to completely destroy the pathogen or pest, but rather to reduce the damage below economically significant values. The development and commercialization of specific biocontrol agents is a lengthy and expensive process. Many biocontrol products are legally classified as pesticides and are subject to the same regulatory requirements as synthetic pesticides (Segall, 1995). New product registration is often costly and time-consuming (Deacon, 1993). There also has been a fair amount of concern about the unexpected negative impacts of releasing biocontrol agents outside their natural range (Howarth, 1991; Longworth, 1987; Pimentel, 1980). These issues have generated interest in finding naturally occurring materials, with pest-controlling properties, that do not require formal registration. In conjunction with the use of these products, major changes in overall crop production and soil management systems also might be necessary (Hoy, 1992).

Among the available candidates for natural products with pest and disease control potential, the composting process and compost have been relatively widely studied. It is well established that the thermophilic conditions and intense microbial competition during composting kill or inactivate nearly all the microorganisms that cause plant, animal, or human disease (Farrell, 1993; Bollen, 1996; Avgelis, 1992). One exception to this is the Tobacco Mosaic Virus, which may survive composting (Hoitink, 1976a). After disease-infested crop residues are composted, the material is no longer infectious and can be safely applied to farm fields without contributing to disease problems. In contrast, uncomposted residues can serve as an inoculum for infection of subsequent crops. The composting process has proven effective at destroying plant pathogenic nematodes, bacteria, viruses, and fungi (Bollen, 1996; Lopez-Real, 1985; Bollen, 1985).

Mature compost, in many cases, also contains natural organic chemicals and beneficial microorganisms that kill or suppress disease-causing microorganisms. Several mechanisms of action for this phenomenon have been proposed (Hoitink, 1986a; Hoitink, 1986b; Hoitink, 1991a; Hoitink, 1993), including interspecific competition for nutrients, production of chemicals with antimicrobial activity, production of enzymes that destroy the cell walls of pathogens, and changes in the environmental conditions of the soil, which inhibit pathogen growth.

Among the various compostable materials, wood bark has been the most widely studied as a growth medium for potted plants and for its disease-suppressive properties. The original intentions for using wood bark were to find a beneficial use for this abundant and inexpensive waste material and to reduce the consumption of peat, a relatively expensive and nonrenewable natural product. Since some barks contain phytotoxic compounds (Self, 1978), composting became a routine practice for reducing phytotoxicity. Early observations indicated that the composted bark also reduced disease severity in potted plants (Gerrettson-Cornell, 1976; Hoitink, 1975; Hoitink, 1976a and 1976b; Hoitink, 1977; Hoitink, 1980; Malek, 1975). Today, the use of composted bark as a fungicide is widely accepted (Hoitink, 1993). This allows growers to reduce their reliance on chemical fungicides (Daft, 1979) and to decrease operating costs and worker hazards associated with chemical fungicide applications.

Figures 32 and 33 show the effectiveness of composted bark potting mixes on decreasing the severity of root rot in greenhouse-grown poinsettias. Figure 34 illustrates the superior ability of two composts to suppress plant damage in potting media inoculated with high levels of the root pathogen *Fusarium oxysporum*. In both situations, the composted materials provided much better disease reduction results than did peat.

Disease suppression following compost application also has been demonstrated under field conditions. Compost has been shown to increase the stand density of alfalfa in fields where yields have been declining, presumably because of increased disease pressure (Logsdon, 1993). Compost also can significantly decrease the severity of gummy stem blight and damping off diseases in squash, as well as suppress rootknot nematodes and Rhizoctonia root rot (Logsdon, 1993). Some composts have been found to suppress dollar spot disease in putting greens as shown in Figure 35 (Nelson, 1991). There are several remarkable features regarding this discovery, including:

- Large differences in the effectiveness of different composts. One municipal sewage sludge compost was moderately effective, while another was completely ineffective.

- Large variations in suppressiveness at different sampling times during the same year, especially when compared to fungicide treatments.

- Very large between-year performance of some composts, but not others. The varied effectiveness of the composts is similar to behavior of other biocontrol products (Deacon, 1993).

One of the most critical limitations to increased use of biocontrol products, with a few exceptions, is the inability of these products to control diseases with the same consistency as synthetic chemicals. The lack of consistent performance is probably the result of complex interactions between environmental conditions that modify plant susceptibility to a pathogen and/or change the relative infective potential of the pathogen (Burdon, 1992; Dickman, 1992; Couch, 1960). The suppressive activity of a biocontrol agent also will vary under different environmental conditions (Baker, 1982; Mandelbaum, 1990). Plants that are stressed by lack of moisture and/or elevated temperatures, or whose root systems have been damaged by nematode or insect attack, are more vulnerable to disease. In general, fungal activity is regulated by substrate and nutrient availability, water content of the medium, oxygen and carbon dioxide levels, and the presence of other organisms that compete for materials required by the fungus. Depending upon which combination of these conditions is present at a given time, disease incidence can vary greatly, as shown in Figure 35. Conditions were so favorable to pathogen development for the October 18, 1990, sample date, for example, that even chemical treatment was only partially effective. In such conditions, the ability of a single biocontrol agent to consistently suppress diseases is limited. A possible solution to this problem may come from the use of antagonistic fungi and actinomycetes from composted pine bark and sand mixtures (Hardy, 1995). About 80 percent of these fungi and actinomycetes are disease-suppressive when inoculated into sterilized compost. Compost containing a mixture of suppressive organisms also is expected to contain pathogen growth under a wide range of conditions, as shown in the hypothetical case illustrated in Figure 36. In this case, consistent suppression of the pathogen by either *Trichoderma*, *Bacillus*, or a mixture of the two cannot occur, because the activity range of the pathogen falls outside the range of either organism or a combination of them. In contrast, at least one member of the much more diverse group of antagonists found in compost will be active under any of the conditions where the pathogen is active. Thus, a likely consequence of increased antagonist diversity is improved biocontrol under the wide-ranging conditions encountered in the field.

Some composts also can modify bacterial populations in the plant rhizosphere (the root–soil interface) and increase the abundance of bacteria that are antagonists of various root-pathogenic fungi, as shown in Figure 37. In laboratory situations, however, fungi isolated from compost suppressed spore germination in the highly beneficial mycorrhizal fungus *Glomus mosseae* (Calvet, 1992). Some composts contain microorganisms that suppress pathogenic fungi in soil and on the plant root system, whereas other composts may actually have deleterious effects on root microorganisms.

In addition to controlling fungal pathogens, compost also can modify the severity of nematode damage (Roy, 1976). One study examined the effects of MSW compost on populations of rootknot nematode and plant growth in pot and field studies (Marull, 1997). In pot studies, the addition of 33 percent by weight of compost significantly increased plant growth and significantly decreased nematode populations in the mixes. Sixty-six percent compost, however, did not stimulate plant growth or decrease nematode populations any better than the 33 percent treatment. The lack of growth stimulation at 66 percent compost was probably the result of inhibition of plant growth at high rates of compost addition (see Iannotti, 1994, for example). The effects of municipal waste compost on nematode populations are detailed in Table 8.

Table 8

Effects of MSW Compost on Populations of the Root-Parasitic Nematode *Meloidogyne Javanica* and on the Incidence of Root Galls in a Field Study

Treatment	Nematode Numbers per 250 cm^3 Soil		Nematodes per g Root		Root Gall Severity	
	Non-fumigated	Fumigated	Non-fumigated	Fumigated	Non-fumigated	Fumigated
Control	4380	7460	17,000	13,450	90	91
+ compost	1410[a]	1100[a]	8,010[a]	7,760[a]	80	73

[a] Indicates a significant decrease as a result of compost application.
Source: Marull, 1997 (Table 6)

Compost's ability to suppress soil-borne pathogens is well documented; however, a few reports indicate compost extracts (or "teas") also have disease-reducing properties against foliar pathogens. Extracts of spent mushroom substrate, cattle manure, and sheep manure compost proved ineffective at controlling apple scab in orchards (Yohalem, 1994). Results with control of red pine seedling blight were more encouraging, with extracts of spent mushroom substrate from three different sources providing significant reductions in disease severity (Figure 38). There are often substantial differences in the effectiveness of extracts from different sources (Nelson, 1991). At the present time, producing compost extracts is not a well-developed technology. Individuals devise various procedures for preparing the extracts, with substantial differences in the procedures among different workers. Many variables exist in the production of such materials, including the type and age of compost used and the incubation and extraction procedures employed. While these extracts may have pathogen-suppressing activity in some cases, it is not clear if that activity is due to chemicals in the extracts or to the microorganisms whose growth is favored during extract preparation. This topic is likely to be a fruitful area for future research.

The specific mechanisms for disease suppression by compost have not been clearly identified. Understanding of the mechanisms behind compost's suppression of pathogens is complicated by the fact that raw plant materials, which are composted, might contain organic compounds with antipathogen properties (Qasem, 1995). In some cases, these organic compounds are destroyed by the time compost is mature. It is not always certain, however, that the composts used for disease suppression studies are mature. A further complication is the ability of some uncomposted waste materials to affect populations of plant pathogenic fungi and pests, such as nematodes (Bridge, 1996), and for some composts to have no greater disease-suppressive properties than the raw materials from which they are made (Figure 39) (Asirifi, 1994). If an immature compost is used, some of its pathogen-suppressive activity may be due to the raw input components rather than compost constituents. As a result, the mechanism of pathogen suppression may vary in compost from lot to lot, in some cases as the result of chemical control and in other cases of biocontrol. Based on some of the references cited in Chapter 1, the relative abundance of different microbial species varies with compost age and composition of input; therefore, biotic composition of different composts is probably also a variable feature among the work of different researchers. Some composts also contain VOCs with pathogen-suppressive activity (Tavoularis, 1995).

The use of compost for disease suppression involves a remarkably complicated set of interactions among various microorganisms, chemical constituents of composted materials, and plant tissues. It is evident that, in certain situations and with particular specialized growth media, such as container mixes that include bark, compost is an effective substitute for synthetic chemicals in the control of pathogens. Since there is a very reduced availability of synthetic fungicides and a decreased willingness to use them, further research on compost-based disease control is highly desirable. Several studies indicate that compost is an excellent source of disease-suppressive bacteria and fungi, and, therefore, it is likely to be a fruitful source of biological materials for biotechnological applications. Since chemicals in compost also can affect pathogens, compost may be a useful source of natural products with biocontrol activity.

Figure 32

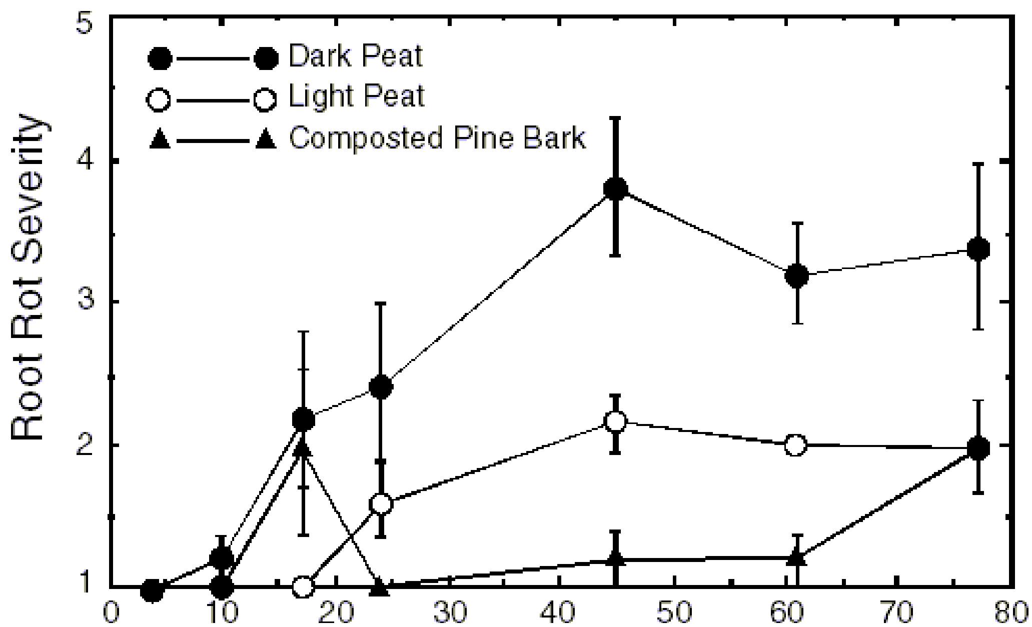
Root Systems of Poinsettia Plants

Plants were grown in mixes containing peat without disease-suppressive properties (top row), disease-suppressive peat (middle row), or disease-suppressive composted pine bark (bottom row). Light-colored roots are healthy, while dark-colored roots are diseased.

Source: Hoitink, 1991a and 1991b

Figure 33

Severity of Root Rot of Poinsettia Plants



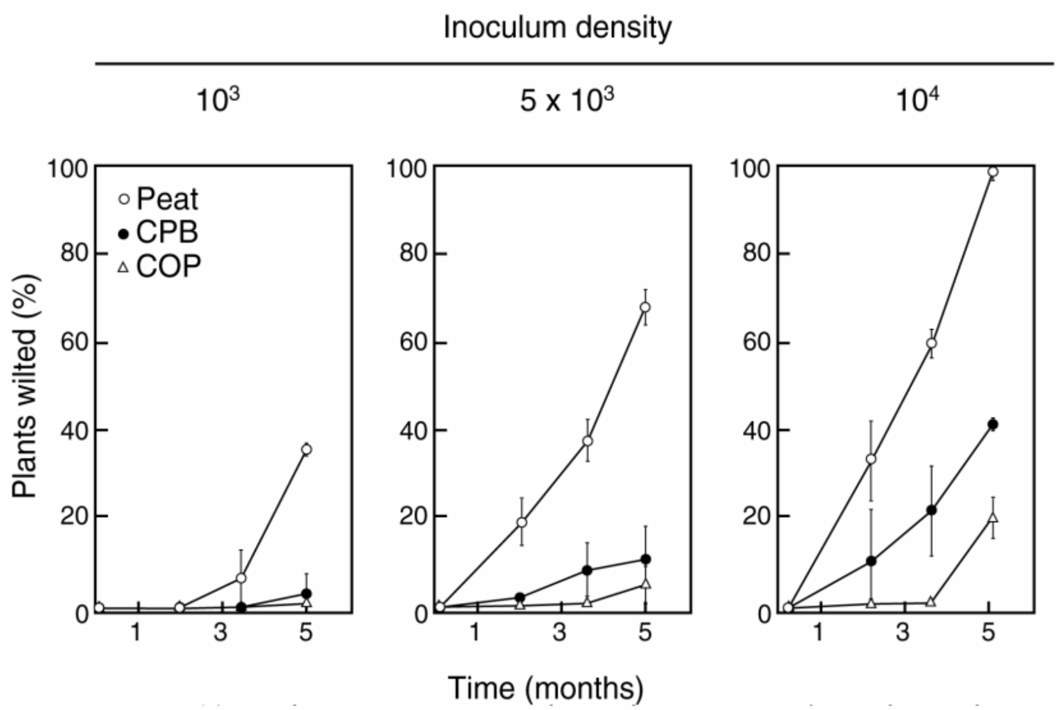
Time (Days) of Plant Growth

Plants were grown in mixes containing peat without disease-suppressive properties, disease-suppressive peat, or disease-suppressive composted bark. Root rot severity ranges from 1 to 5, with 5 being the most severe.

Source: Boehm, 1992

Figure 34

Disease Severity (Percentage of Wilted Carnation Plants) When Grown in Mixes Containing Peat and Sand (Peat), Composted Bark and Sand (CPB), or Composted Olive Pumice* and Sand (COP)

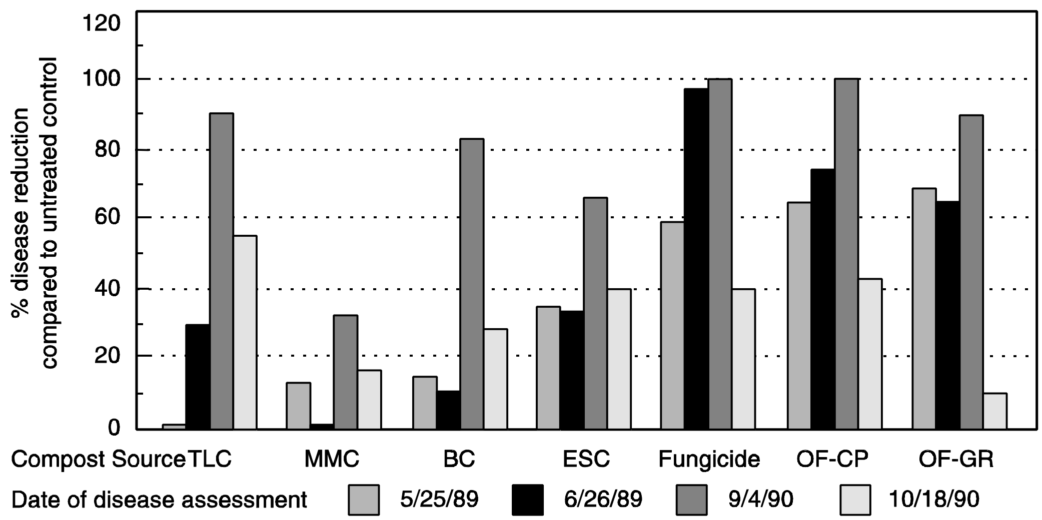


*Olive pumice is the waste generated during the processing of olives for oil.

Source: Pera, 1989

Figure 35

Relative Disease-Suppressing Ability of Composts and Fertilizers Against the Turfgrass Disease Dollar Spot

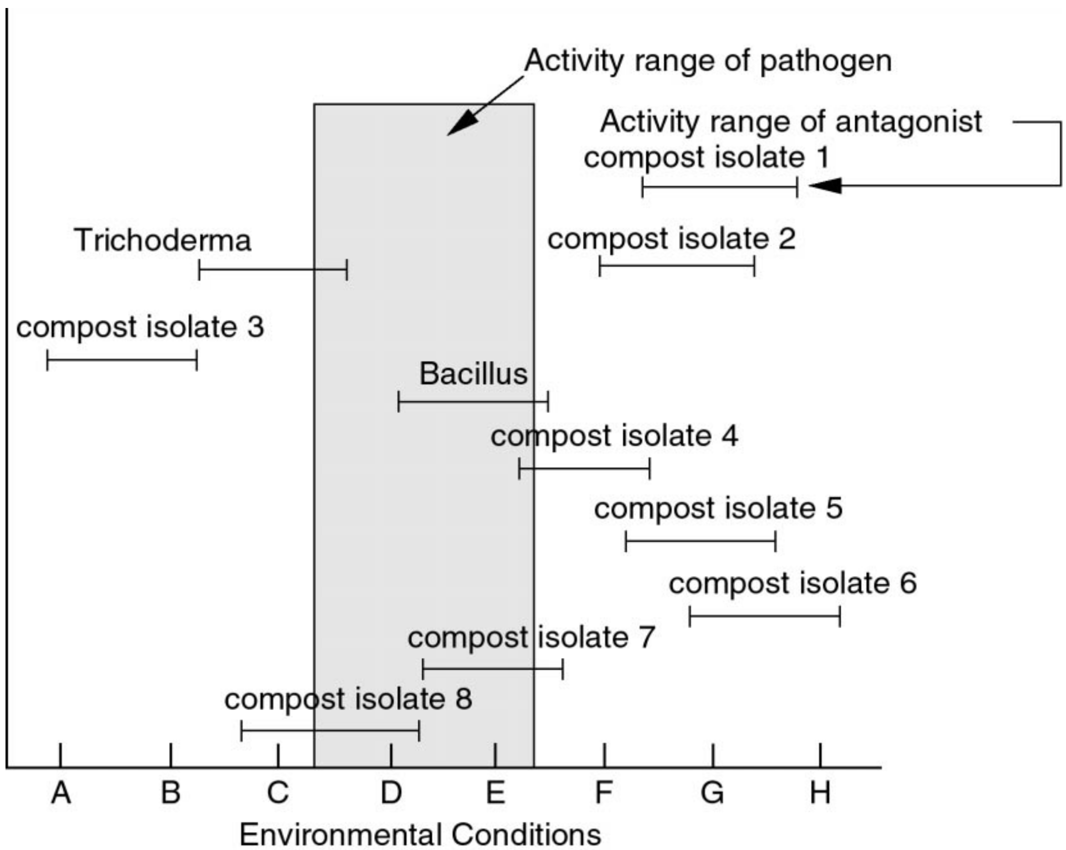


Abbreviations: TLC=turkey litter compost, MMC=manure compost, BC=brewery waste compost, ESC=Endicott sludge compost, fungicide=propiconazole, OF-CP=an organic (not composted) fertilizer, and OF-GR=another organic (not composted) fertilizer.

Source: Nelson, 1991 (Table 3)

Figure 36

A Hypothetical Case to Illustrate the Value of a Diverse Disease-Suppressive Population in Comparison to Single Antagonists or a Mixture of Two Antagonists

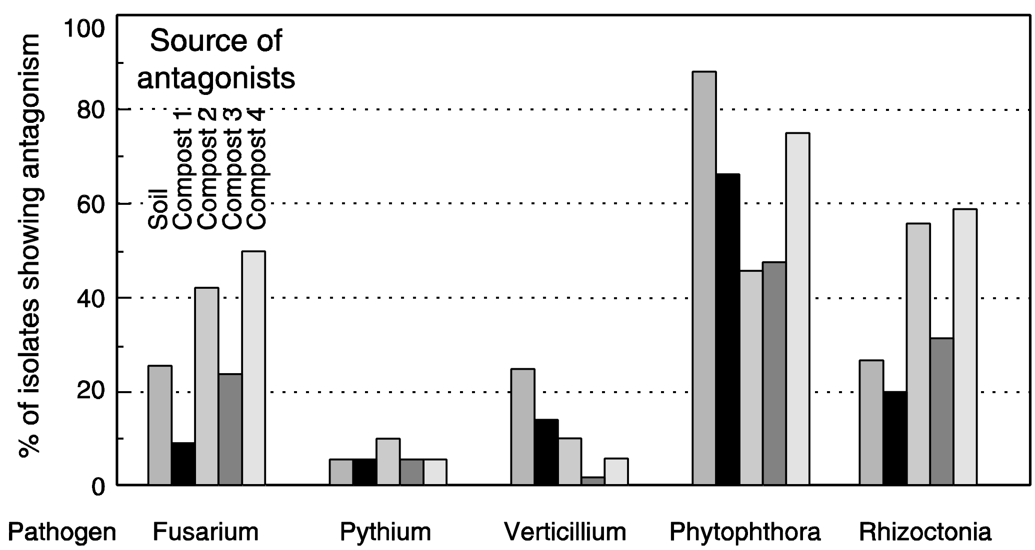


An "environmental condition" is a particular combination of moisture content, substrate and nutrient availability, and oxygen and carbon dioxide content that favors or reduces activity of an organism.

Source: Cole, unpublished

Figure 37

Incidence of Bacteria With Suppressive Activity Toward Fungal Pathogens on Plant Root Systems Growing in Soil or Compost



Source: Alvarez, 1995 (Table 4)