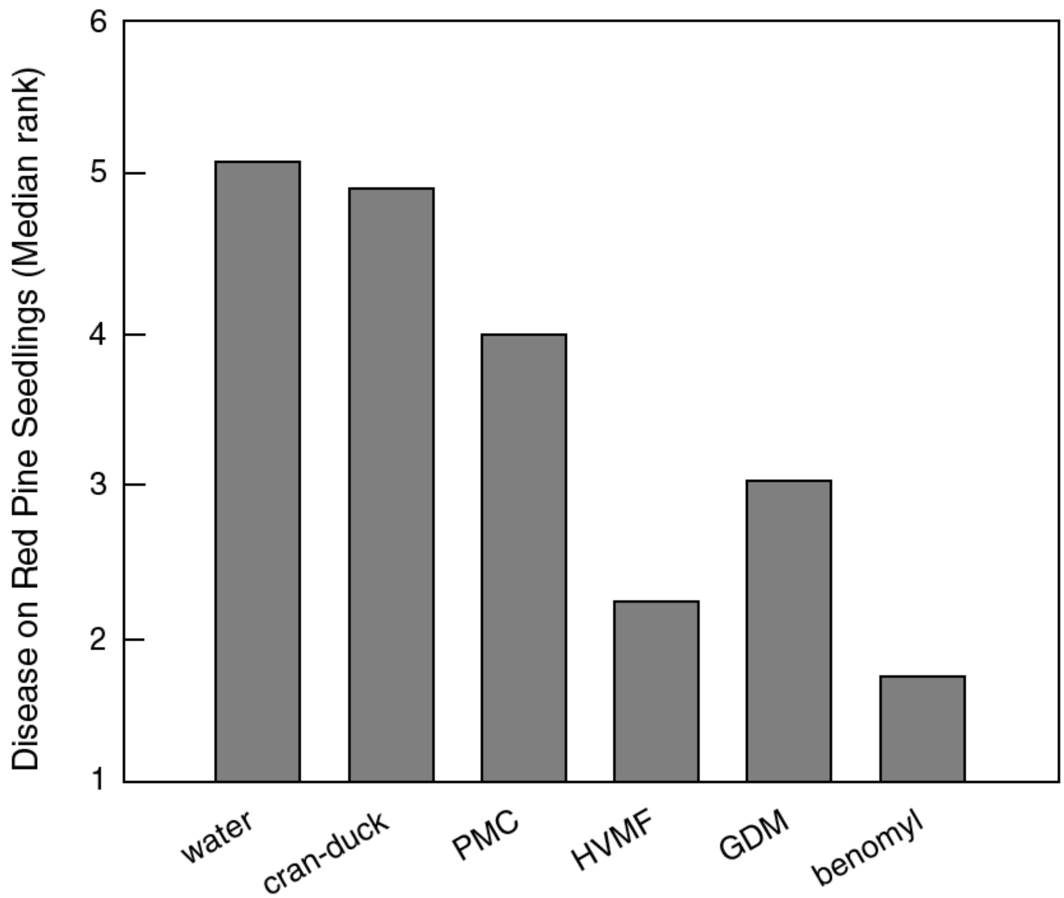
Figure 38

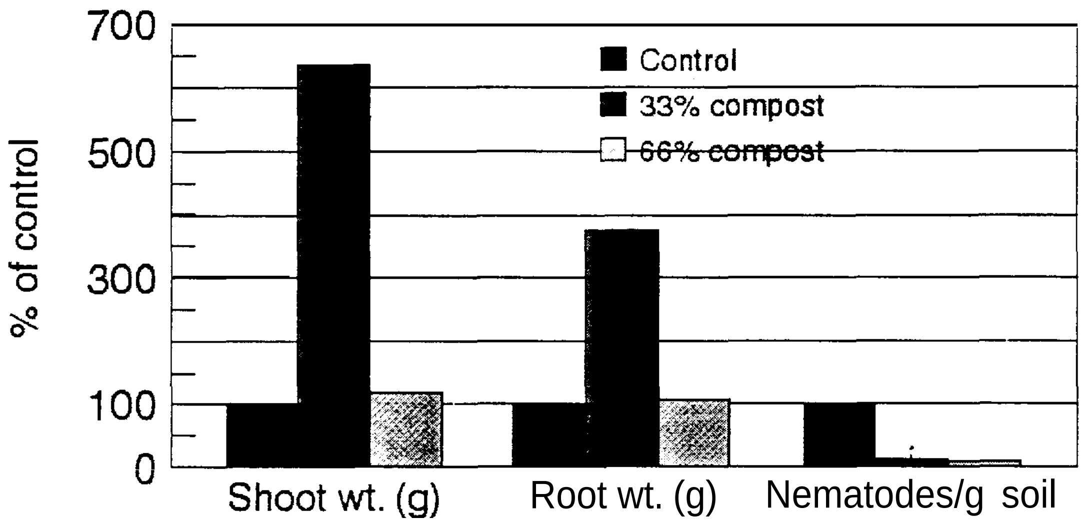
Influence of Extracts of Spent Mushroom Substrate (PMC, HVMF, and GDM) and a Compost Prepared From Cranberry Waste and Duck Manure on Disease Severity of Red Pine Blight



Source: Yohalem, 1994 (Figure 5)

Figure 39

Effects of MSW Compost on Green Pepper Growth and Populations of the Root-Parasitic Nematode *Meloidogyne Javanica* in a Pot Study



Source: Marull, 1997 (Table 2)

References

Alvarez, B., S. Gagné, and H. Antoun. "Effect of Compost on Rhizosphere Microflora of the Tomato and on the Incidence of Plant Growth-promoting Rhizobacteria." *Applied and Environmental Microbiology* 61 (1995): 194-199.

Asirifi, K.N., W.C. Morgan, and D.G. Parbery. "Suppression of Sclerotinia Soft Rot of Lettuce With Organic Soil Amendments." *Australian Journal of Experimental Agriculture* 34 (1994): 131-136.

Avgelis, A.D. and V.I. Manios. "Elimination of Cucumber Green Mottle Mosaic Tobamovirus by Composting Infected Cucumber Residues." *Acta Horticulturae* 302 (1992): 311-314.

Baker, K.F. and R.J. Cook. *Biological Control of Plant Pathogens*, 176. St. Paul, MN: The American Phytopathological Society, 1982.

Bollen, G.J. "The Fate of Plant Pathogens During Composting of Crop Residues." In *Composting of Agricultural and Other Wastes*, edited by J.K.R. Gasser, 282-290. London: Elsevier Applied Science Publishers, 1985.

Bollen, G.J. and D. Volker. "Phytohygienic Aspects of Composting." In *The Science of Composting*, edited by M. de Bertoldi, P. Bert, and P. Tiziano, 233-246. London: Blackie Academic and Professional, 1996.

Bridge, J. "Nematode Management in Sustainable and Subsistence Agriculture." *Annual Review of Phytopathology* 34 (1996): 201-225.

Burdon, J.J. "The Growth and Regulation of Pathogenic Fungal Populations." In *The Fungal Community*, edited by G.C. Carroll and D.T. Wicklow, 173-181. New York, NY: Marcel Dekker, Inc., 1992.

Calvet, C., J.M. Barea, and J. Pera. "In Vitro Interactions Between the Vesicular-arbuscular Mycorrhizal Fungus *Glomus mosseae* and Some Saprophytic Fungi Isolated From Organic Substrates." *Soil Biology and Biochemistry* 24 (1992): 775-780.

Couch, H.B. and J.R. Bloom. "Influence of Environment on Diseases of Turfgrasses. I. Effect of Nutrition, pH, and Soil Moisture on Sclerotinia Dollar Spot." *Phytopathology* 50 (1960): 761-763.

Daft, G.C., H.A. Poole, and H.A.J. Hoitink. "Composted Hardwood Bark: A Substitute for Steam Sterilization and Fungicide Drenches for Control of Poinsettia Crown and Root Rot." *HortScience* 14 (1979): 185-187.

Deacon, J.W. and L.A. Berry. "Biocontrol of Soil-borne Plant Pathogens: Concepts and Their Application." *Pesticide Science* 37 (1993): 417-426.

Dickman, A. "Plant Pathogens and Long-term Ecosystem Changes." In *The Fungal Community*, edited by G.C. Carroll and D.T. Wicklow, 499-520. New York, NY: Marcel Dekker, Inc., 1992.

Farrell, J.B. "Fecal Pathogen Control During Composting." In *Science and Engineering of Composting*, edited by H.A.J. Hoitink and H.M. Keener, 282-300. Worthington, OH: Renaissance Publications, 1993.

Gerrettson-Cornell, L., F.R. Humphreys, and S.R. Townsend. "Results of a Preliminary Investigation on the Use of *Pinus radiata* Bark Against *Phytophthora cinnamomi* Rands." *Phyton* 34 (1976): 3-6.

Hardy, G.E. and K. Sivasithamparam. "Antagonism to Fungi and Actinomycetes Isolated From Composted Eucalyptus Bark to Phytophthora Drechsleri in a Steamed and Non-steamed Composted Eucalyptus Bark-amended Container Medium." *Soil Biology and Biochemistry* 27 (1995): 243-246.

Hoitink, H.A.J. "Composted Bark, A Lightweight Growth Medium With Fungicidal Properties." *Plant Disease* 64 (1980): 142-147.

Hoitink, H.A.J., M.J. Boehm, and Y. Hadar. "Mechanisms of Suppression of Soilborne Plant Pathogens in Compost-amended Substrates." In *Science and Engineering of Composting*, edited by H.A.J. Hoitink and H.M. Keener, 601-621. Worthington, OH: Renaissance Publications, 1993.

Hoitink, H.A.J. and P.C. Fahy. "Basis for the Control of Soilborne Plant Pathogens With Composts." *Annual Review of Phytopathology* 24 (1986): 93-114.

Hoitink, H.A.J., L.J. Herr, and A.F. Schmitthenner. "Survival of Some Plant Pathogens During Composting of Hardwood Tree Bark." *Phytopathology* 66 (1976b): 1369-1372.

Hoitink, H.A.J., Y. Inbar, and M.J. Boehm. "Status of Compost-amended Potting Mixes Naturally Suppressive to Soilborne Diseases of Floricultural Crops." *Plant Disease* 75 (1991a): 869-873.

Hoitink, H.A.J., Y. Inbar, and M.J. Boehm. "Compost Can Suppress Soil-borne Diseases in Container Media." *American Nurseryman* 178 (September 1991b): 91-94.

Hoitink, H.A.J. and G.A. Kuter. "Effects of Composts in Growth Media on Soilborne Plant Pathogens." In *The Role of Organic Matter in Modern Agriculture*, edited by Y. Chen and Y. Avnimelech, 289-306. Dordrecht, Netherlands: Martinus Nyhoff Publishers, 1986.

Hoitink, H.A.J. and H.A. Poole. "Composted Bark Mediums for Control of Soil-borne Plant Pathogens." *American Nurseryman* 144(5) (1976a): 15, 88-89.

Hoitink, H.A.J., A.F. Schmitthenner, and L.J. Herr. "Composted Bark for Control of Root Rot in Ornamentals." *Ohio Reporter* 60 (1975): 25-26.

Hoitink, H.A.J., D.M. VanDoren, Jr., and A.F. Schmitthenner. "Suppression of Phytophthora cinnamomi in a Composted Hardwood Bark Potting Medium." *Phytopathology* 67 (1977): 561-565.

Howarth, F.G. "Environmental Impacts of Classical Biological Control." *Annual Review of Entomology* 36 (1991): 485-509.

Hoy, M.A. "Biological Control of Arthropods: Genetic Engineering and Environmental Risks." *Biological Control* 2 (1992): 166-170.

Iannotti, D.A., M.E. Grebus, B.L. Toth, L.V. Madden, and H.A.J. Hoitink. "Oxygen Respirometry to Assess Stability and Maturity of Composted Municipal Solid Waste." *Journal of Environmental Quality* 23 (1994): 1177-1183.

Logsdon, G. "Using Compost for Plant Disease Control." *BioCycle* 34(10) (1993): 33-36.

Longworth, J.F. "Biological Control in New Zealand: Policy and Procedures." *New Zealand Entomologist* 10 (1987): 1-7.

Lopez-Real, J. and M. Foster. "Plant Pathogen Survival During the Composting of Agricultural Organic Wastes." In *Composting of Agricultural and Other Wastes*, by J.K.R. Gasser, 291-300. London: Elsevier Applied Science Publishers, 1985.

Malek, R.B. and J.B. Gartner. "Hardwood Bark as a Soil Amendment for Suppression of Plant Parasitic Nematodes on Container Grown Plants." *HortScience* 10 (1975): 33-35.

Mandelbaum, R. and Y. Hadar. "Effects of Available Carbon Source on Microbial Activity and Suppression of *Pythium aphanidermatum* in Compost and Peat Container Media." *Phytopathology* 80 (1990): 794-804.

Marull, J., J. Pinochet, and R. Rodriquez-Kabana. "Agricultural and Municipal Composts Residues for Control of Root-knot Nematodes in Tomato and Pepper." *Compost Science and Utilization* 5(1) (1997): 6-15.

Nelson, E.B. and C.M. Craft. "Suppression of Dollar Spot on Creeping Bentgrass and Annual Bluegrass Turf With Compost-amended Topdressings." *Plant Disease* 76 (1991): 954-958.

Pimentel, D. "Environmental Risks Associated With Biological Controls." *Ecological Bulletin* 31 (1980): 11-24.

Qasem, J.R. and H.A. Abu-Blan. "Antifungal Activity of Aqueous Extracts From Some Common Weed Species." *Annals of Applied Biology*. 127 (1995): 215-219.

Quarles, W. and J. Grossman. "Alternatives to Methyl Bromide in Nurseries -- Disease Suppressive Media." *The IPM Practicioner* 17(8) (1995): 1-13.

Roy, A.K. "Effect of Decaffeinated Tea Waste and Water Hyacinth Compost on the Control of Meloidogyne graminicola on Rice." *Indian Journal of Nematology* 6 (1976): 73-77.

Segall, L. "Marketing Compost as a Pest Control Product." *BioCycle* 36 (1995): 65-67.

Self, R.L.   "Pine Bark in Potting Mixes, Grades and Age, Disease and Fertility Problems." *Proceedings of The International Plant Propogators' Society* 28 (1978): 363-368.

Tavoularis, K., A. Papadaki, and V. Manios.   "Effect of Volatile Substances Released From Olive Tree Leave Compost on the Vegetative Growth of Rhizoctonia solani and Fusarium oxysporum F. sp. lycopersici." *Acta Horticulturae* 382 (1995): 183-186.

Yohalem, D.S., R.F. Harris, and J.H. Andrews. "Aqueous Extracts of Spent Mushroom Substrate for Foliar Disease Control." *Compost Science and Utilization* 2(4) (1994): 67-74.

Chapter 6

Compost-Enhanced Phytoremediation of Contaminated Soil

Phytoremediation is a developing technology in which higher plants and microorganisms associated with plant roots are the active agents for uptake and/or degradation of toxic inorganic and organic compounds in soil and water. This method successfully intercepts nitrate and prevents its transfer from groundwater to surface water. It also is used in a number of applications with organics-contaminated water (Table 9). As indicated in Chapter 4, plants also reduce the erosional transport of contaminated soil when compared to unvegetated material. Given this, phytoremediation provides a straightforward approach to both the degradation and containment of contaminated soil and water, as shown in Figure 40. In this case, contaminated water is stripped of contaminants as it flows past the plant roots, as a result of waste uptake by the plants. Depending on the contaminant, degradation might occur in the rhizosphere (the soil adjacent to plant roots) or within the plant itself. If the compound is not degraded, it will likely volatilize. Regardless of the ultimate fate of the contaminant, once contact with the plant occurs, the water is no longer contaminated. This process might be suitable for soil remediation and/or inexpensive confinement of shallow contaminated water.

Phytoremediation of metal-contaminated soil relies on the ability of plants to accumulate metals at concentrations substantially above those found in the soil in which they grow (Kelly, 1995; Brown, 1994; Brown, 1995; Cunningham, 1995; Cornish, 1995). Since plant uptake requires that metals be in an environmentally mobile form (Schnoor, 1995), the use of compost is likely to be an impediment to successful phytoremediation, as compost immobilizes toxic metals (see Chapter 4 for examples).

Table 9

Phytoremediation of Contaminated Soil or Water[a]

Contaminated Material	Contaminants	Results
Water (hydroponic system in laboratory)	Nitrobenzene	Complete uptake from solution
Soil	Trinitrotoluene	Essentially complete treatment
Soil	Trichloroethylene	Enhanced mineralization
Contaminated soil	Pentachlorophenol and phenanthrene	Enhanced mineralization
Soil	Trinitrotoluene	Enhanced degradation

[a] Adapted from Schnoor, 1995.

Numerous reports indicate that plants can take up and degrade toxic organic compounds in soil, while other work indicates microorganisms in the rhizosphere are very competent degraders of soil-borne organics. Rhizosphere microorganisms are able to degrade the herbicide 2,4-dichlorophenoxyacetic acid (2,4-D) much more rapidly than those in root-free soil and convert a higher percentage of carbon in 2,4-D to carbon dioxide, as shown in Figure 41 (Shann, 1994). In contrast, enhanced mineralization of ^{14}C-labeled pyrene was not found in rhizosphere soil (Schwab, 1994 and Schwab, 1995). These apparently conflicting results are due to the relatively high mobility of 2,4-D in soil as compared to pyrene. As a result of rapid water uptake by plants, desorption of contaminants from soil may be the rate-limiting step for degradation (Schnoor, 1995). Based on the examples shown in Table 9, plants might decrease remediation time, as well as enhance the complete destruction of target compounds. Further work is required to define the characteristics of plants and soil systems before an understanding of the appropriateness of phytoremediation for particular situations can be attained.

Phytoremediation has very large economic advantages over mechanically intensive technologies because plants require little maintenance in comparison to machinery. The following are the major constraints of the method:

- Relatively slow remediation rates. The time until site closure can be years. This constraint means that phytoremediation cannot be the method of choice when rapid site closure is a necessity.

- Lack of information about the fate of compounds in planted soil. Losses of volatile ^{14}C from ^{14}C-labeled naphthalene are about 50 percent higher in planted soil than in unplanted soil (Watkins, 1994). Poor recovery is probably the result of inefficient capture of volatile organics and/or carbon dioxide and can be solved by the development of better test systems. Chapter 2 details the issue of whether partial degradation of xenobiotics, followed by conversion of metabolites into immobile forms, is a sufficient remedy for contamination. This same issue arises with phytoremediation, because immobilization of carbon from xenobiotics in conjugated forms is promoted in planted systems. The results, presented in Figure 42, indicate that studies of the fate of xenobiotic residues when they enter soil would be appropriate. Because of the complexity of plants, microorganisms, and soil systems and the uncertainties of chemical behavior in these systems, further research is necessary before this method can be employed on a large scale.

- Difficulties in establishing plants in toxic, contaminated matrices, and in compacted and barren materials that are not conducive to plant growth. This constraint can be overcome by the addition of compost. A small body of research indicates that compost can reduce toxicity of contaminated soil (probably through the adsorption of the toxic compounds to organic matter in the compost). Figure 43 compares the growth of herbicide-sensitive weed species when grown in contaminated material from an agrichemical retail site. In the absence of compost, little weed growth occurs, but addition of compost detoxifies the soil and good weed growth occurs. In this case, plant growth also accelerated decontamination when compared with soil without compost addition, as shown in Table 10.

The amount of compost needed to achieve beneficial effects varies with the project goals. For example, 20 percent w/w compost is sufficient to maximize plant growth in herbicide-contaminated soil (Figure 44), but 40 percent compost is needed to accelerate herbicide degradation in the same soil (Figure 45). The decrease in remediation time for relatively degradable compounds like metolachlor strongly suggests that phytoremediation—if healthy and vigorous plants can be established—has considerable potential for enhancing bioremediation activities, particularly in situations such as urban brownfields (Chapter 4), where cost and time are important components in choosing a remediation method.

Table 10

Effects of Mix Composition and Planting on Pesticide Degradation, Following 40 Days of Plant Growth[a]

Mixture	Treatment	Trifluralin	Metolachlor	Pendimethalin
		mg kg^{-1} soil		
Initial concentration	None	2.2 ± 0.9	3.0 ± 0.2	11.8 ± 5.1
100% contamination	Planted	0.80 ± 0.82 (0.27)[b]	3.4 ± 5.0 (0.25)	1.6 ± 0.4 (0.02)
100% contamination	Not planted	0.48 ± 0.77 (0.77)	0.99 ± 1.4 (0.25)	1.8 ± 0.4 (0.02)
50:50 soil	Planted	nd[c]	nd	0.5 ± 0.6 (0.01)
50:50 soil	Not planted	0.52 ± 0.53 (0.07)	0.18 ± 0.16 (<0.001)	1.0 ± 0.2 (0.02)
50:50 compost	Planted	0.36 ± 0.33 (0.02)	nd	1.5 ± 0.6 (0.02)
50:50 compost	Not planted	0.44 ± 0.69 (0.08)	2.8 ± 3.4 (0.29)	2.6 ± 3.4 (0.12)

[a] Values are means ± standard deviations of duplicate extractions of four replications per treatment.
[b] Values in parentheses indicate the probability that the values are less than experiences from dilution alone (based on a one-tailed t-test for means of unequal variance).
[c] nd = not detected.

Source: Liu, 1995

Figure 40

Potential Fates of Xenobiotics in Planted Soils

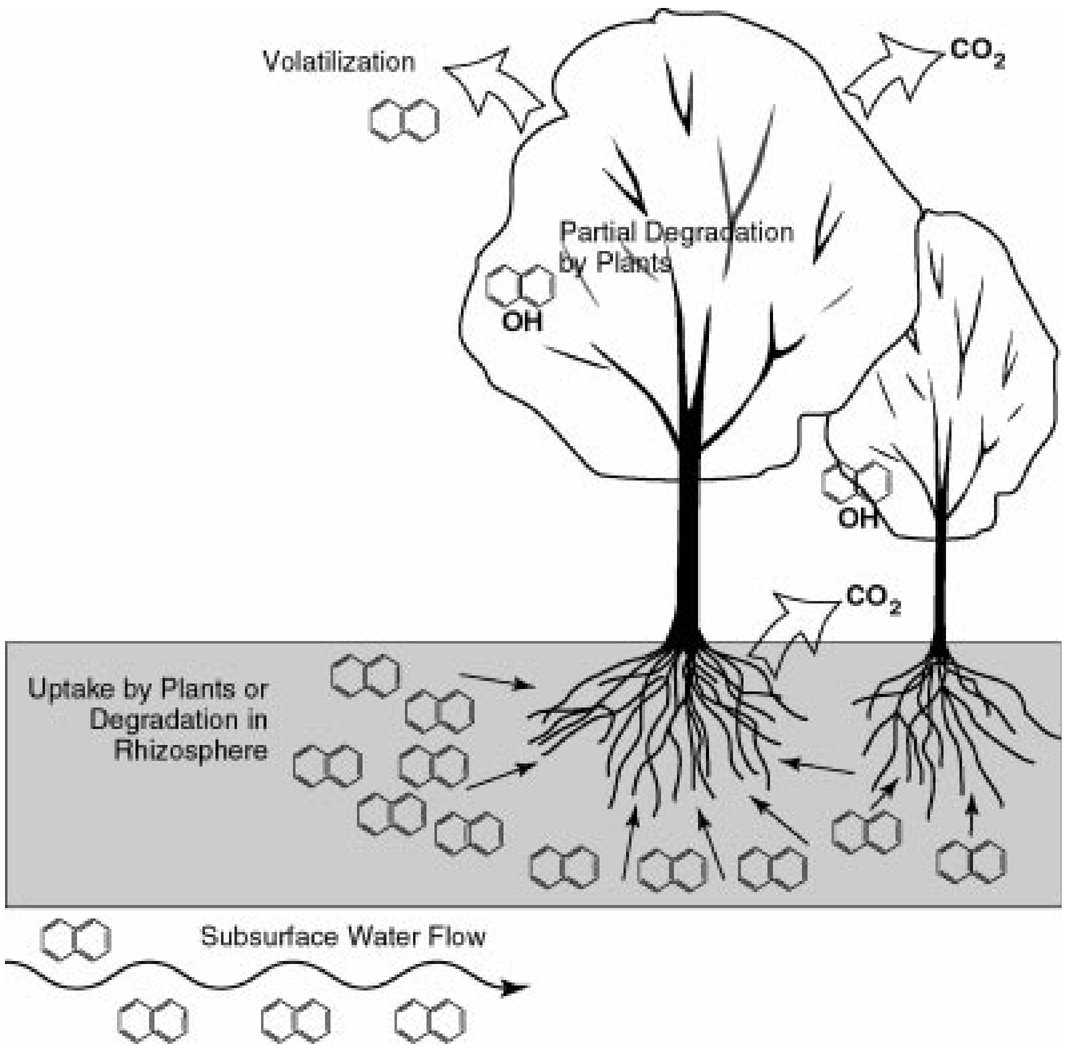
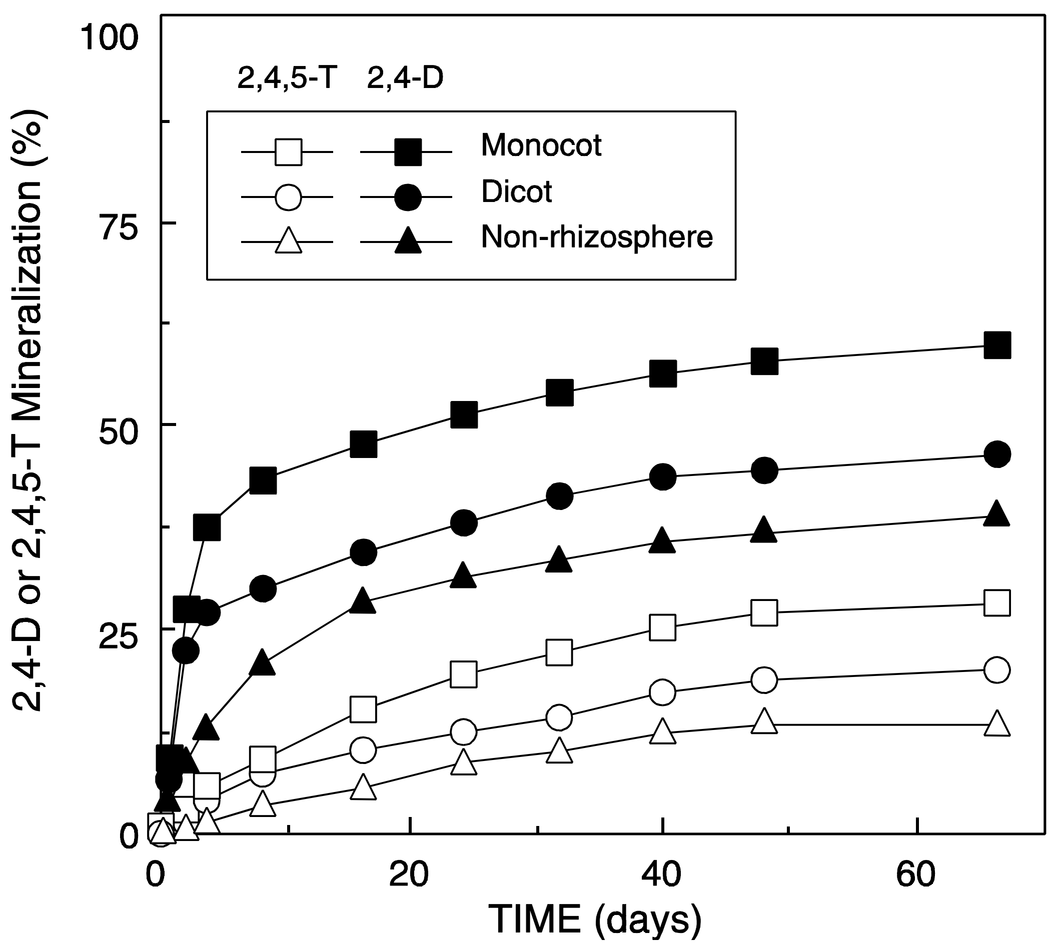


Figure 41

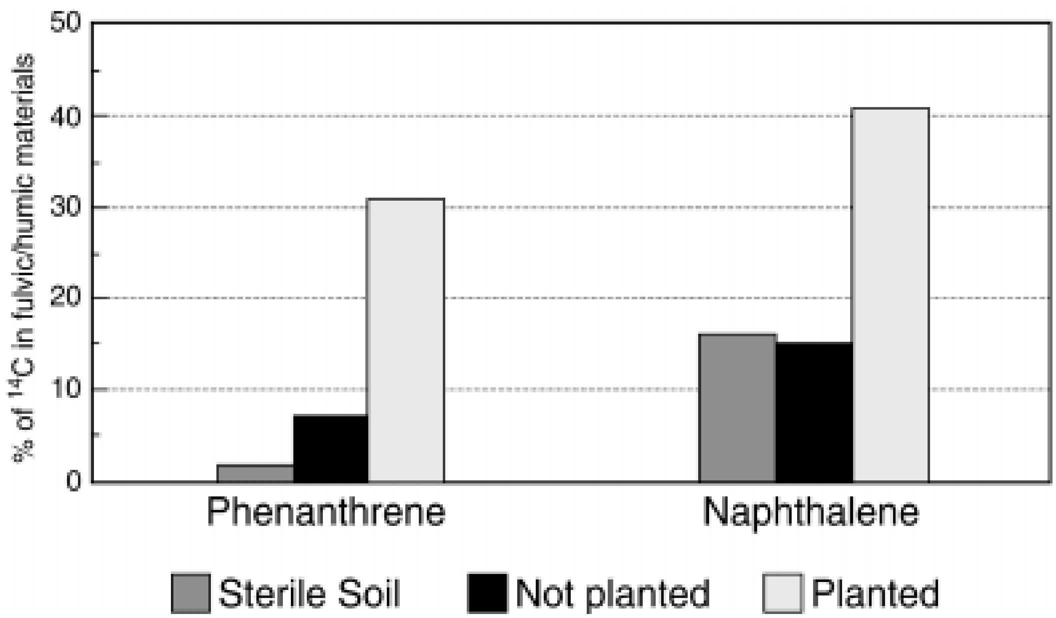
Enhanced Degradation Rates and Mineralization Percentage in Rhizosphere Versus Non-rhizosphere Soil



Source: Shann, 1994

Figure 42

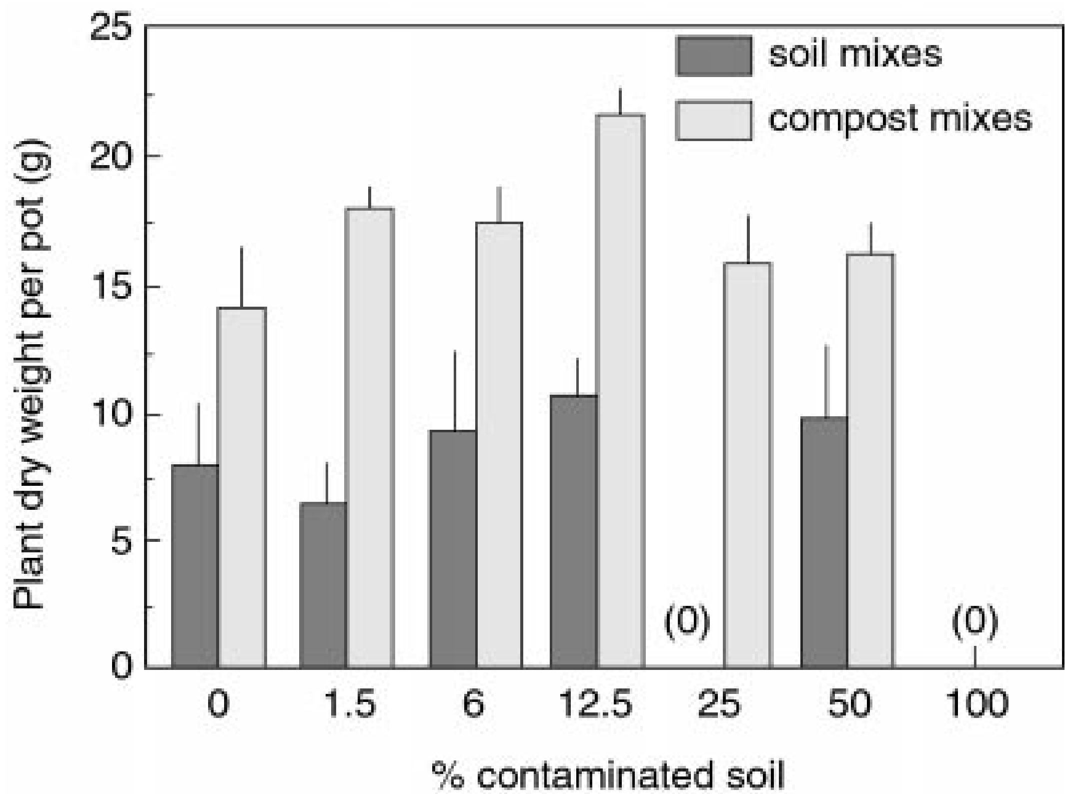
Influence of Plants on Immobilization of ^{14}C From Aromatic Compounds in Soil



Source: Walton, 1994 (Table 1)

Figure 43

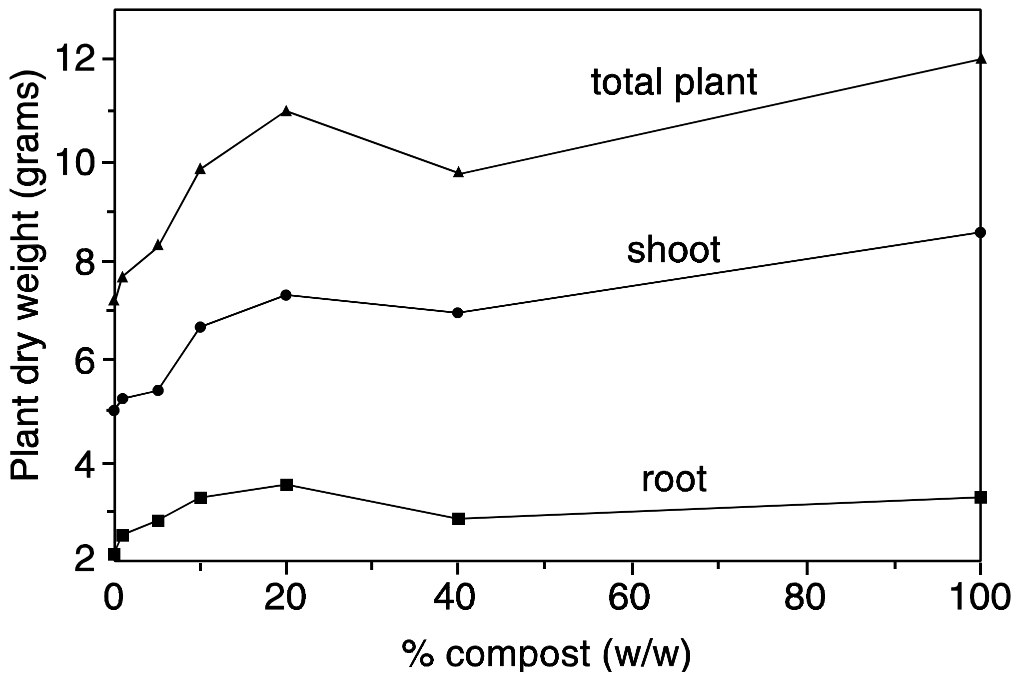
Reduction of Phytotoxicity in Herbicide-Contaminated Soil by Compost



Source: Cole, 1994

Figure 44

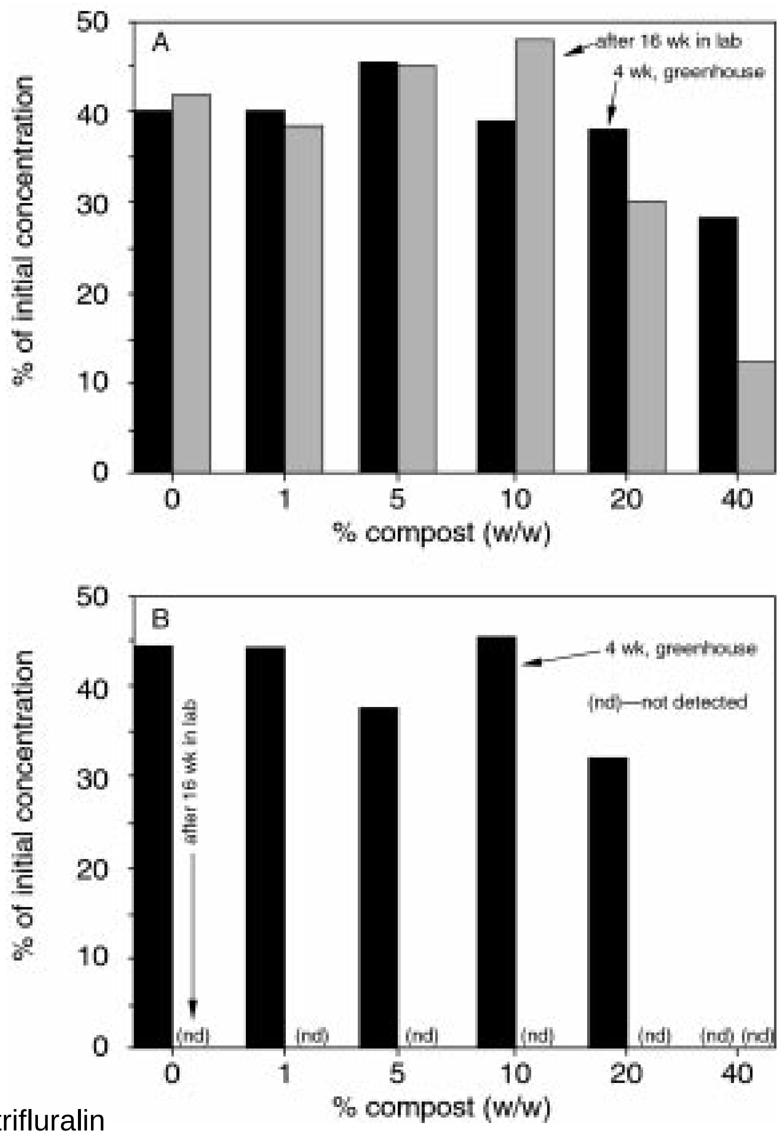
Effect of Amount of Compost Added on Plant Growth in Contaminated Soil



Source: Liu, 1996

Figure 45

Effect of Amount of Compost Added on Rates of Pesticide Degradation in Contaminated Soil



A=Degradation of trifluralin
B=Degradation of metolachlor

Source: Liu, 1996

References

Brown, S.L., R.L. Chaney, J.S. Angle, and A.J.M. Baker. "Phytoremediation Potential of *Thlaspi caerulescens* and Bladder Campion for Zinc- and Cadmium-contaminated Soil." *Journal of Environmental Quality* 23 (1994): 1151-1157.

Brown, S.L., R.L. Chaney, J.S. Angle, and A.J.M. Baker. "Zinc and Cadmium Uptake by Hyperaccumulator *Thlaspi caerulescens* and Metal Tolerant *Silene vulgaris* Grown on Sludge-amended Soils." *Environmental Science and Technology* 29 (1995): 1581-1585.

Cornish, J.E., W.C. Goldberg, R.S. Levine, and J.R. Benemann. "Phytoremediation of Soils Contaminated With Toxic Elements and Radionuclides." In *Bioremediation of Inorganics*, edited by R.E. Hinchee, J.L. Means, and D.R. Burris, 55-63. Columbus, OH: Battalle Press, 1995.

Cunningham, S.D., W.R. Berti, and J.W. Haung. "Remediation of Contaminated Soil and Sludges by Green Plants." In *Bioremediation of Inorganics*, edited by R.E. Hinchee, J.L. Means, and D.R. Burris, 33-54. Columbus, OH: Battalle Press, 1995.

Kelly, R.J. and T.F. Guerin. "Feasibility of Using Hyperaccumulating Plants to Bioremediate Metal-contaminated Soil." In *Bioremediation of Inorganics*, edited by R.E. Hinchee, J.L. Means, and D.R. Burris, 25-32. Columbus, OH: Battalle Press, 1995.

Liu, X. and M.A. Cole. "Minimum Effective Compost Addition for Remediation of Pesticide Contaminated Soil." In *The Science of Composting*, edited by M. de Bertoldi, P. Sequi, B. Lemmes, and T. Papi, 903-912. London: Blackie Academic and Professional, 1996.

Schnoor, J.L., L.A. Licht, S.C. MiCutcheon, N.L. Wolf, and L.H. Carriera. "Phytoremediation of Organic and Nutrient Contaminants." *Environmental Science and Technology* 29 (1995): 318A-323A.

Schwab, A.P. and M.K. Banks. "Biologically Mediated Dissipation of Polyaromatic Hydrocarbons in the Root Zone." In *Bioremediation Through Rhizosphere Technology*, edited by T.A. Anderson and J.R. Coats, 132-141. Washington, DC: American Chemical Society, 1994.

Schwab, A.P., M.K. Banks, and M. Arunachalam. "Biodegradation of Polycyclic Aromatic Hydrocarbons in Rhizosphere Soil." In *Bioremediation of Recalcitrant Organics*, edited by R.E. Hinchee, D.B. Anderson, and R.E. Hoeppel, 23-29. Columbus, OH: Battelle Press, 1995.

Walton, B.T., A.M. Hoylman, M.M. Perez, T.A. Anderson, T.R. Johnson, E.A. Guthrie, and R.F. Christman. "Rhizosphere Microbial Communities as a Plant Defense Against Toxic Substances in Soil." In *Bioremediation Through Rhizosphere Technology*, edited by T.A. Anderson and J.R. Coats, 82-92. Washington, DC: American Chemical Society, 1994.

Watkins, J.W., D.L. Sorensen, and R.C. Sims. "Volatilization and Mineralization of Naphthalene in Soil-grass Microcosms." In *Bioremediation Through Rhizosphere Technology*, edited by T.A. Anderson and J.R. Coats, 123-131. Washington, DC: American Chemical Society, 1994.

Chapter 7

Development of Special-Purpose (Customized) Composts

The majority of the research described in this report was conducted with little discrimination among composts, other than their ready availability. Where different types or ages of compost were compared, substantial differences were found in the ability of the compost to accelerate degradation of organic compounds (Chapter 2) and in disease-suppressive ability (Chapter 5). Compost maturity is certainly a factor in revegetation studies, since numerous researchers have reported that immature composts are phytotoxic. The relatively high success rate for various projects, in spite of the apparently random selection of compost, strongly suggests that particular activities of compost can be enhanced, thereby increasing the effectiveness of the compost. Composts of this type are referred to as "tailor-made" or "designer" composts. The term "special-purpose compost" is used in this chapter to describe composts that are specially treated during production to enhance specific attributes, produced from particular feedstocks to increase activity, to which specific microorganisms have been added, and to which constituents other than organic feedstocks have been added.

In addition to relatively random selection of compost for their research, most researchers conducted their studies with unamended compost. Substantial literature indicates minerals play a major role in controlling the environmental fate and availability of both organic and inorganic components (Hassett, 1989; Ziekle, 1989; Scow, 1993; Dixon, 1977). Little of this work, however, has been applied to improving compost. This chapter describes several cases where the performance of compost was significantly enhanced by special treatment.

The special treatment of feedstock has the potential to improve compost’s metal removal capabilities (Chang, 1995). A recent study conducted with sewage sludge serves as a precedent for potential improvement of metal-binding activity of biosolids compost. In the study, various additions were made to a sewage sludge culture. Copper-binding—but not cadmium-binding—activity varied substantially among the initial cultures (Figure 46). In addition, particular treatments significantly increased the absorption capacity of the cultures for particular metals. It is likely that the same type of process could be used to develop biosolids compost for the types of applications described in Chapter 4.

The metal-binding capacity of composts can be improved by the addition of inorganic materials. For example, the addition of soluble iron and/or phosphate salts to compost increases lead immobilization as a result of forming complex lead-iron-phosphate minerals. Similarly, research by several investigators indicates that some clay minerals interact with lead to form lead-containing minerals in which the bioavailability of the lead is remarkably low (Ryan, no date). Addition of such clays may enhance the ability of compost to decrease lead availability. This suggestion raises the issue of whether immobilization of metals is a sufficient endpoint for remediation (see Chapter 4). Nevertheless, decreased lead availability provides an illustration of the potential for improving the desirable characteristics of compost.

One promising technique in bioremediation is the establishment of desirable microorganisms in soil by adding them as an inoculant (Brown, 1993). This process is referred to as "bioaugmentation." One of the common problems with bioaugmentation is the difficulty in establishing exogenous microorganisms in the contaminated soil (Alexander, 1994; Van Veen, 1997). The addition of microorganisms in compost often results in a 2- to 15-fold increase in bacterial and fungal populations for at least 6 weeks after adding the compost to contaminated soil (Cole, 1996). It appears from these results that the compost protects organisms from predation and other problems that ordinarily result in their loss when added to soil. If this statement is true, then production of composts containing particularly good degraders of pollutants could be a viable approach to microbial introductions into soil.

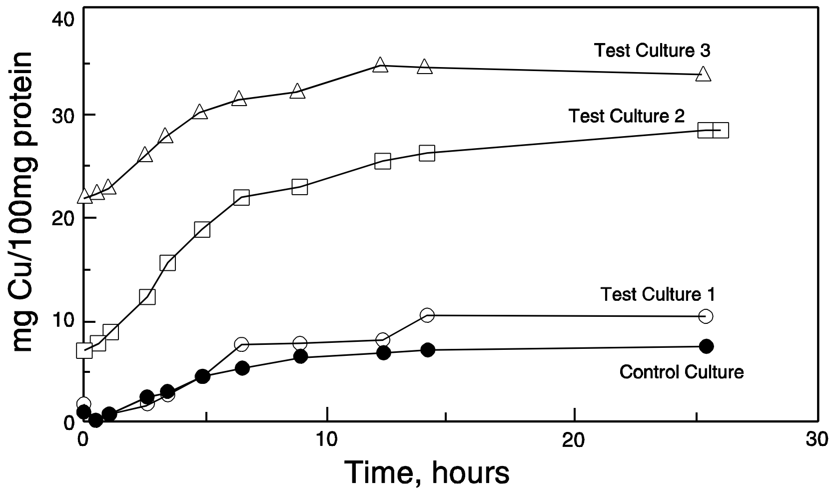
Disease-suppressive organisms isolated from compost can be added to compost at high populations (Hoitink, 1990). The resulting compost has better disease-suppressing activity than uninoculated compost (Hoitink, 1993). In addition, compost with more consistent disease suppression can be produced by isolating antagonistic organisms from compost, propagating them in the laboratory, and adding them back to raw materials prior to composting (Nakasaki, 1996). Both of these examples support the suggestion that compost used for bioremediation can be improved in the same manner.

Several studies in Chapter 3 demonstrate that compost biofilter performance improves substantially after an extended exposure time to contaminated air. This behavior is strongly suggestive of selection for a highly competent population of degrading organisms in the compost. The poor performance of the filters initially might be attributed to the lack of appropriate organisms in sufficient numbers in the starting material. If this interpretation is correct, then isolation of appropriate microorganisms from effective biofilters and introduction into ineffective biofilters may be a rapid method for improving filter performance.

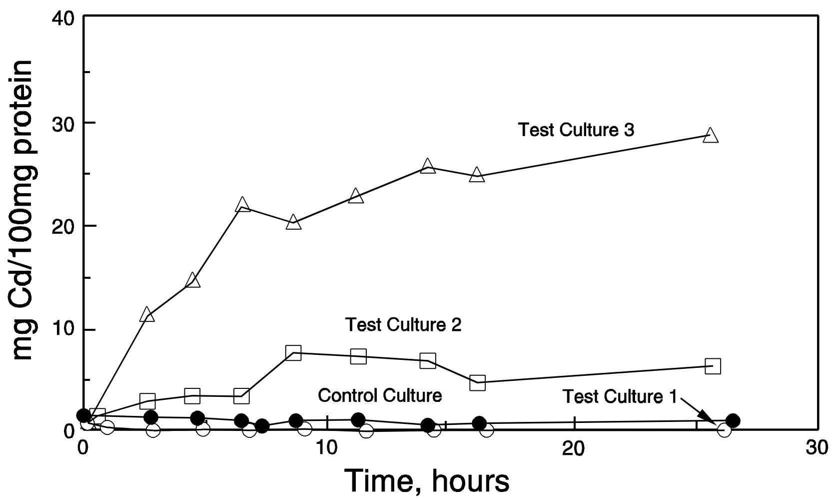
Several references in Chapter 1 demonstrate that microbial populations are large and that their biodiversity is high during the composting process and in mature compost. Since the environmental conditions during composting are radically different from those experienced by organisms in most natural environments, it is possible that compost-derived organisms might have abilities not found in the microbial populations of soil and water. For this reason, further studies on microbial ecology of compost are likely to have beneficial effects, not only for the composting industry but also for uses of compost-based materials.

Figure 46

Enhancement of Metal-Binding Capacity of Sewage Sludge Cultures by Nutrient Amendment and Prior Exposure to Subtoxic Concentrations of Copper and Cadmium



Effect of culture acclimation and stimulation of copper uptake efficiencies.



Effect of culture acclimation and stimulation of cadmium uptake efficiencies.

There is substantial diversity among organisms in terms of their ability to accumulate metals. Given the diversity of organisms in different composts and the wide range of composition among composts produced from different raw materials (see Chapter 1), it is likely that substantial variations in metal-binding ability will be found among different composted materials.

Source: Chang, 1995

References

Alexander, M. *Biodegradation and Bioremediation*, 226-247. San Diego: Academic Press, 1994.

Brown, R.A., W. Mahaffey, and R.D. Norris. “In Situ Bioremediation: The State of the Practice.” In *In Situ Bioremediation: When Does It Work?*, 121-135. Washington, DC: National Academy Press, 1993.

Chang, D., K. Fukushi, and S. Ghosh. “Stimulation of Activated Sludge Cultures for Enhanced Heavy Metal Removal.” *Water Environment Research* 67 (1995): 822-827.

Cole, M.A., X. Liu, and L. Zhang. “Plant and Microbial Establishment in Pesticide-Contaminated Soils Amended With Compost.” In *Bioremediation Through Rhizosphere Technology*, edited by T.A. Anderson and J.R. Coats, 210-222. Washington, DC: American Chemical Society, 1994.

Dixon, J.B. and S.B. Weed. *Minerals in Soil Environments*. Madison, WI: Soil Science Society of America, Inc., 1977.

Hassett, J.J. and W.L. Banwart. “The Sorption of Nonpolar Organics by Soils and Sediments.” In *Reactions and Movement of Organic Chemicals in Soils*, edited by B.L. Sawhney and K. Brown, 31-44. Madison, WI: Soil Science Society of America, Inc., 1989.

Hoitink, H.A.J. “Production of Disease Suppressive Compost and Container Media, and Microorganism Culture for Use Therein.” U.S. Patent 4,960,348. February 13, 1990.

Hoitink, H.A.J., M.J. Boehm, and Y. Hadar. “Mechanisms of Suppression of Soilborne Plant Pathogens in Compost-amended Substrates.” In *Science and Engineering of Composting*, edited by H.A.J. Hoitink and H.M. Keener, 601-621. Worthington, OH: Renaissance Publications, 1993.

Nakasaki, K., M. Kubo, and H. Kubota. “Production of Functional Compost Which Can Suppress Phytopathogenic Fungi of Lawn Grass by Inoculating Bacillus subtilis Into Grass Clippings.” In *The Science of Composting*, edited by M. de Bertoldi, P. Bert, and P. Tiziano, 87-95. London: Blackie Academic and Professional, 1996.

Ryan, J.A. and P. Zhang. “Soil Lead Remediation: Is Removal the Only Option?” Unpublished manuscript distributed on the Internet. No date.

Scow, K.M. “Effect of Sorption-desorption and Diffusion Processes on the Kinetics of Biodegradation of Organic Chemicals in Soil.” In *Sorption and Degradation of Pesticides and Organic Chemicals in Soil*, 73-114. Madison, WI: Soil Science Society of America, Inc., 1993.

van Veen, J.A., L.S. van Overbeek, and J.D. van Elsas. “Fate and Activity of Microorganisms Introduced Into Soil.” *Microbiology and Molecular Biology Reviews* 61 (1997): 121-135.

Ziekle, R.C., T.J. Pinnavaia, and M.M. Mortland. "Absorption and Reactions of Selected Organic Molecules on Clay Mineral Surfaces." In *Reactions and Movement of Organic Chemicals in Soils*, edited by B.L. Sawhney and K. Brown. Madison, WI: Soil Science Society of America, Inc., 1989.

Chapter 8

Bibliography

Introduction

Anonymous. *Compost Facility Operating Guide*. Alexandria, VA: The Composting Council, 1994.

BioCycle Staff (eds.). *Composting Source Separated Organics*. Emmaus, PA: The JG Press, Inc., 1994.

Chang, Y. and H.J. Hudson. "The Fungi of Wheat Straw Compost. I. Ecological Studies." *Transactions of the British Mycological Society* 50 (1967): 649-666.

Cole, M.A., L. Zhang, and X. Liu. "Remediation of Pesticide Contaminated Soil by Planting and Compost Addition." *Compost Science and Utilization* 3 (1995): 20-30.

Dalzell, H.W., A.J. Biddlestone, K.R. Gray, and K. Thurairajan. *Soil Management: Compost Production and Use in Tropical and Subtropical Environments.* FAO Soils Bulletin 56. Rome: Food and Agriculture Organization of the United Nations, 1987.

Eastwood, D.J. "The Fungus Flora of Composts." *Transactions of the British Mycological Society* 35 (1952): 215-220.

Fálcon, M.A., E. Corominas, M.L. Pérez, and F. Perestelo. "Aerobic Bacterial Populations and Environmental Factors Involved in the Composting of Agricultural and Forest Wastes of the Canary Islands." *Biological Wastes* 20 (1987): 89-99.

Finstein, M.S., F.C. Miller, and P.F. Strom. "Monitoring and Evaluating Composting Process Performance." *Journal of the Water Pollution Control Federation* 58 (1986): 272-278.

Finstein, M.S., F.C. Miller, and P.F. Strom. "Waste Treatment Composting as a Controlled System." In *Biotechnology, Volume 8*, edited by W. Schonborn, 363-398. Weinheim, Federal Republic of Germany: VCH Verlagsgesellschaft, 1986.

Finstein, M.S., F.C. Miller, P.F. Strom, S.T. MacGregor, and K.M. Psarianos. "Composting Ecosystem Management for Waste Treatment." *Bio/Technology* 1 (1983): 347-353.

Finstein, M.S., and M.L. Morris. "Microbiology of Municipal Soil Waste Composting." *Advances in Applied Microbiology* 19 (1975): 113-151.

Garland, G.A., T.A. Grist, and R.E. Green. "The Compost Story: From Soil Enrichment to Pollution Remediation." *BioCycle* 36 (October 1995): 53-56.

Gasser, J.K.R. *Composting of Agricultural and Other Wastes*. London: Elsevier Applied Science Publishers, 1985.

Godden, B., M. Penninckx, A. Piérard, and R. Lannoye. "Evolution of Enzyme Activities and Microbial Populations During Composting of Cattle Manure." *European Journal of Applied Microbiology and Biotechnology* 17 (1983): 306-310.

Haug, R.T. *The Practical Handbook of Compost Engineering*. Boca Raton, FL: Lewis Publishers, 1993.

Hogan, J.A., F.C. Miller, and M.S. Finstein. "Physical Modeling of the Composting Ecosystem." *Applied and Environmental Microbiology* 55 (1989): 1082-1092.

Hoitink, H.A.J. and H.M. Keener. *Science and Engineering of Composting*. Worthington, OH: Renaissance Publications, 1993.

Jeris, J.S. and W.R. Regan. "Controlling Environmental Parameters for Optimum Composting. II. Moisture, Free Air Space and Recycle." *Compost Science* 14(2) (1973): 8-15.

McKinley, V.L. and J. R.Vestal. "Biokinetic Analyses of Adaptation and Succession: Microbial Activity in Composting Municipal Sewage Sludge." *Applied and Environmental Microbiology* 47 (1984): 933-941.

Nakasaki, K., M. Sasaki, M. Shoda, and H. Kubota. "Change in Microbial Numbers During Thermophilic Composting of Sewage Sludge With Reference to CO_2 Evolution Rate." *Applied and Environmental Microbiology* 49 (1985): 37-41.

Nakasaki, K., M. Sasaki, M. Shoda, and H. Kubota. "Characteristics of Mesophilic Bacteria Isolated During Thermophilic Composting of Sewage Sludge." *Applied and Environmental Microbiology* 49 (1985): 42-45.

Poincelot, R.P. *The Biochemistry and Methodology of Composting*. Connecticut Agricultural Experiment Station Bulletin 127. New Haven, CT: Connecticut Agricultural Experiment Station, 1972.

Rynk, R. (ed.). *On-Farm Composting Handbook*. Ithaca, NY: Northest Regional Agricultural Engineering Service, Cooperative Extension, 1992.

Strom, P.F. "Effect of Temperature on Bacterial Species Diversity in Thermophilic Solid Waste Composting." *Applied and Environmental Microbiology* 50 (1985): 899-905.

Strom, P.F. "Identification of Thermophilic Bacteria in Solid Waste Composting." *Applied and Environmental Microbiology* 50 (1985): 906-913.

Struwe, S. and A. Kjøller. "Changes in Population Structure During Decomposition." In *Microbial Communities in Soil*, edited by V. Jensen, A. Kjøller, and L.H. Sørensen, 149-162. London: Elsevier Applied Science Publishers, 1986.

Tosin, M.F. and C. Bastioli. "Effect of the Composting Substrate on Biodegradation of Solid Materials Under Controlled Composting Conditions." *Journal of Environmental Polymer Degradation* 4 (1996): 55-63.

U.S. EPA. *Composting: Yard and Municipal Solid Waste*. Washington, DC, no date.

Vestjens, T. "Tunnel Composting Technology." *Mushroom Journal* 531 (1994): 14-15.

Waksman, S.A. and T.C. Cordon. "Thermophilic Decomposition of Plant Residues in Composts by Pure and Mixed Cultures of Microorganisms." *Soil Science* 47 (1939): 217-225.

Waksman, S.A., T.C. Cordon, and N. Hulpoi. "Influence of Temperature Upon the Microbiological Population and Decomposition Processes in Composts of Stable Manure." *Soil Science* 47 (1939): 83-113.

Waksman, S.A., W.W. Umbreit, and T.C. Cordon. "Thermophilic Actinomycetes and Fungi in Soils and in Composts." *Soil Science* 47 (1939): 37-61.

Webley, D.M. "The Microbiology of Composting. I. The Behaviour of the Aerobic Mesophilic Bacteria Flora of Composts and Its Relation to Other Changes Taking Place During Composting." *Proceedings of the Society of Applied Bacteriology* 2 (1947): 83-99.

Remediation of Soils Contaminated With Toxic Organic Compounds

Anonymous. "Hazardous Waste Composting." *The Hazardous Waste Consultant* (June/July 1992): 1.12-1.13.

Arndt, W., E. Schindlbeck, H. Parlar, and F. Korte. "Behavior of Organophosphorus Insecticides in Garbage and Waste Composting." *Chemosphere* 10 (1981): 1035-1040.

Buswell, J.A. "Potential of Spent Mushroom Substrate for Bioremediation Purposes." *Compost Science and Utilization* 2 (1994): 31-36.

Cole, M.A., X. Liu, and L. Zhang. "Plant and Microbial Establishment in Pesticide-contaminated Soils Amended With Compost." In *Bioremediation through Rhizosphere Technology,* edited by T.A. Anderson and J.R. Coats, 210-222. Washington, DC: American Chemical Society, 1994.

Cole, M.A., X. Liu, and L. Zhang. "Effect of Compost Addition on Pesticide Degradation in Planted Soils." In *Bioremediation of Recalcitrant Organics*, edited by R.E. Hinchee, D.B. Anderson, and R.E. Hoeppel, 183-190. Columbus, OH: Battelle Press, 1995.

Cole, M.A., L. Zhang, and X. Liu. "Remediation of Pesticide Contaminated Soil by Planting and Compost Addition." *Compost Science and Utilization* 3 (1995): 20-30.

Cook, B.D., P.B. Bloom, and T.R. Halbach. "A Method for Determining the Ultimate Fate of Synthetic Chemicals During Composting." *Compost Science and Utilization* 2 (1994): 42-50.

Crawford, S.L., G.E. Johnson, and F.E. Goetz. "The Potential for Bioremediation of Soils Containing PAHs by Composting." *Compost Science and Utilization* 1 (1993): 41-47.

de Bertoldi, M., P. Bert, and P. Tiziano. *The Science of Composting*. London: Blackie Academic and Professional, 1996.

Diaz, L.F., G.M. Savage, and C.G. Golueke. "Stabilization of Hazardous Wastes Through Biotreatment." In *The Science of Composting*, by M. de Bertoldi, P. Bert, and P. Tiziano, 849-862. London: Blackie Academic and Professional, 1996.

Fantoni, A., P. Muraro, C. Picco, and G. Zorzi. "Biodegradation of Thiram in Composting Process." In *The Science of Composting*, by M. de Bertoldi, P. Bert, and P. Tiziano, 1152-1156. London: Blackie Academic and Professional, 1996.

Fogarty, A.M. and O.H. Tuovinen. "Microbiological Degradation of Pesticides in Yard Waste Composting." *Microbiological Reviews* 55 (1991): 225-233.

Fyock, O.L., S.B. Nordrum, S. Fogel, and M. Findley. "Pilot Scale Composting of Petroleum Production Sludges." In *Third Annual Symposium on Environmental Protection in the Energy Industry: Treatment and Disposal of Petroleum Sludges*, edited by K.L. Sublette and T.M. Harris. Tulsa, OK: University of Tulsa, 1991.

Hogan, J.A. "Composting for Soil Remediation." In *Biological Treatment of Hazardous Wastes*, by G.A. Lewandowski and L.J. DeFilippi. New York, NY: John Wiley and Sons, Inc., 1998.

Kabrick, R.M. and J.R. Coover. "Composting as BDAT for Solvent (F Wastes) Contaminated Soils." In *Environmental Engineering: Proceedings of the 1989 Speciality Conference*, edited by J.F. Malina. New York, NY: American Society of Civil Engineers, 1989.

Kamnikar, B. "Bioremediation of Contaminated Soil." *Pollution Engineering* 24 (November 1, 1992): 50-52.

Lemmon, C.R. and H.M. Pylypiw, Jr. "Degradation of Diazinon, Chlorpyrifos, Isofenphos, and Pendimethalin in Grass and Compost." *Bulletin of Environmental Contamination and Toxicology* 48 (1992): 409-415.

Martens, R. "Concentrations and Microbial Mineralization of Four to Six Ring Polycyclic Aromatic Hydrocarbons in Composted Municipal Waste." *Chemosphere* 11 (No date): 761-770.

McNabb, D.H., R.L. Johnson, and I. Guo. "Aggregation of Oil- and Brine-contaminated Soil to Enhance Bioremediation." In *Hydrocarbon Bioremediation*, by R.E. Hinchee, B.C. Alleman, R.E. Hoeppel, and R.N. Miller, 296-302. Boca Raton, FL: Lewis Publishers, 1994.

Michel Jr., F.C., D. Graeber, L.J. Forney, and C.A. Reddy. "Fate of Lawn Care Pesticides During the Composting of Yard Trimmings." In *The Science of Composting*, by M. de Bertoldi, P. Bert, and P. Tiziano, 1230-1231. London: Blackie Academic and Professional, 1996.

Nishio, M. and S. Kusano. "Fluctuation Patterns of Microbial Numbers in Soil Applied With Compost." *Soil Science and Plant Nutrition* 26 (1980): 581-593.

Okeke, B.C., J.E. Smith, A. Paterson, and I.A. Watson-Craik. "Aerobic Metabolism of Pentachlorophenol by Spent Sawdust Culture of 'Shiitake' Mushroom." *Biotechnology Letters* 15 (1993): 1077-1080.

Racke, K.D. and C.R. Fink. "Fate of Organic Contaminants During Sewage Sludge Composting." *Bulletin of Environmental Contamination and Toxicology* 42 (1989): 526-533.

Rao, N., H.E. Grethlein, and C.A. Reddy. "Mineralization of Atrazine During Composting With Untreated and Pretreated Lignocellulosic Substrates." *Compost Science and Utilization* 3 (1995): 38-46.

Regan, Sr., R.W. "Use of SMS as a Compost Matrix to Degrade Pesticide Residuals." *Compost Science and Utilization* 2 (1994): 56-62.

Rhodes, S.H. and P.C. Peck. "Composting for Remediation of Soil Contaminated With Pharmaceutical Residues." In *Bioremediation of Recalcitrant Organics*, by R.E. Hinchee, R.E. Hoeppel, and D.B. Anderson, 341-348. Boca Raton, FL: Lewis Publishers, 1995.

Savage, G.M., L.F. Diaz, and C.G. Golueke. "Disposing of Hazardous Wastes by Composting." *BioCycle* 26(1) (1985): 31-34.

Sikora, L.J., D.D. Kaufman, M.A. Ramirez, and G.B. Wilson. "Degradation of Pentachlorophenol and Pentachloronitrobenzene in a Laboratory Composting System." In *Land Disposal of Hazardous Waste: Proceedings of the 8th Annual Research Symposium*, edited by D.W. Shultz, 372-382. Washington, DC: U.S. EPA, 1982.

Snell, J.R. *Rate of Biodegradation of Toxic Organic Compounds While in Contact With Organics Which Are Actively Composting*. PB84-193150. Washington, DC: National Technical Information Service, 1982.

Tan, E., C.H. Ho, W.H. Griest, and R.L. Tyndall. "Mutagenicity of Trinitrotoluene and Its Metabolites Formed During Composting." *Journal of Environmental Toxicology and Environmental Health* 36 (1992): 165-175.

Valo, R. and M. Salkinoja-Salonen. "Bioreclamation of Chlorophenol-contaminated Soil by Composting." *Applied Microbiology and Biotechnology* 25 (1986): 68-75.

Vogtmann, H., P.V. Fragstein, and P. Draeger. "The Degradation of Agrochemicals During Composting." *Proceedings of the Second International Symposium on Peat in Agriculture and Horticulture*. Bet Dagan: Hebrew University of Jerusalem, 1983.

Weston, R.F., Inc. *Windrow Composting Demonstration for Explosives-Contaminated Soils at the Umatilla Depot Activity Hermiston, Oregon*. Report CETHA-TS-CR-93043, 1993.

Williams, R.T., P.S. Ziegenfuss, and P.J. Marks. *Field Demonstration—Composting of Explosives-Contaminated Sediments at the Louisiana Army Ammunition Plant (LAAP): Final Report*. West Chester, PA: Roy F. Weston, Inc., 1988.

Williams, R.T., P.S. Ziegenfuss, and W.E. Sisk. "Composting of Explosives and Propellant Contaminated Soils Under Thermophilic and Mesophilic Conditions." *Journal of Industrial Microbiology* 9 (1992): 137-144.

Yare, B.S. "A Comparison of Soil-phase and Slurry-phase Bioremediation of PNA-containing Soils." In *On-Site Bioreclamation*, edited by R.E. Hinchee and R.F. Olfenbuttel, 173-187. Boston: Butterworth-Heinemann, 1991.

Compost-Based Biofilters for Treatment of Contaminated Air and Wastewater Streams

Bohn, H.L. "Compost Scrubbers of Malodorous Air Streams." *Compost Science* 17 (Winter 1976): 15-17.

Eitzer, B.D. "Volatile Chemical Emissions at Composting Facilities Are Significantly Below Workplace Guidelines." *Frontiers of Plant Science* 47 (Fall 1994): 2-3.

Everwijn, T.S., F.R. Hoffman, H. Ramhit, C.E. Schultz, and J.W.A. Verwaart. *Bodemreinigingstechnieken*, 68. Amsterdam: Uitgeverij Boom, 1992.

Fischer, K. "Environmental Impact of Composting Plants." In *The Science of Composting*, edited by M. de Bertoldi, P. Bert, and P. Tiziano, 81-86. London: Blackie Academic and Professional, 1996.

Hwang, Y., T. Matsuo, K. Hanaki, and N. Suzuki. "Removal of Odorous Compounds in Wastewater by Using Activated Carbon, Ozonation, and Aerated Biofilter." *Water Research* 28 (1994): 2309-2319.

Pinnette, J.R., M.D. Giggey, G.E. Hendry, and C.M. Richardson. "Moisture Balance of an Open Biofilter." *Compost Science and Utilization* 1(2) (1993): 8-22.

Pomeroy, R.D. "Biological Treatment of Odorous Air." *Journal of the Water Pollution Control Federation* 54 (1982): 1541-1545.

Prokop, W.H. and H.L. Bohn. "Soil Bed System for Control of Rendering Plant Odors." *Journal of the Air Pollution Control Association* 35 (1985): 1332-1338.

Selby, M.A. "Soil Filters at Treatment Plant." *BioCycle* 27 (July 1986): 33.

Stewart, W.C. “Biofiltration for the Capture and On-site Destruction of VOC's in Aerosol Can Puncturing and Recycling Operations.” Unpublished manuscript, no date.

Stewart, W.C. and R.R. Thom. “Test Results and Economics of Using an Innovative, High-rate, Vapor-phase Biofilter in Industrial Applications.” Unpublished manuscript, no date.

Van der Hoek, K.W. and J. Oosthoek. “Composting: Odour Emission and Odour Control by Biofiltration.” In *Composting of Agricultural and Other Wastes*, edited by J.K.R. Gasser, 271-281. London: Elsevier Applied Science Publishers, 1985.

Van Langenhove, H., E. Wuyts, and N. Schamp. “Elimination of Hydrogen Sulfide From Odorous Air by a Wood Bark Biofilter.” *Water Research* 20 (1986):1471-1476.

Vembu, K. and C.S. Walker. “Biofiltration Holds VOCs, Odors at Bay.” *Environmental Protection* (February 1995): 27-30, 58.

Walker, J.M. “Control of Composting Odors.” In *Science and Engineering of Composting*, edited by H.A.J. Hoitink and H.M. Keener, 185-241. Worthington, OH: Renaissance Publications, 1993.

Williams, T.O. and F.C. Miller. “Biofilters and Facility Operations.” *BioCycle* 33 (November 1992): 75-79.

Potential for Reclamation of Mine Spoils and Brownfields With Compost

Allievi, L., A. Marchesini, C. Salardi, V. Piano, and A. Ferrari. “Plant Quality and Soil Residual Fertility Six Years After a Compost Treatment.” *Bioresource Technology* 43 (1993): 85-89.

Autio, W.R., D.W. Greene, D.R. Cooley, and J.R. Schupp. “Improving the Growth of Newly Planted Apple Trees.” *HortScience* 26 (1991): 840-843.

Baker, A.J.M. and R.R. Brooks. “Terrestrial Higher Plants Which Hyperaccumulate Metallic Elements—A Review of Their Distribution, Ecology, and Phytochemistry.” *Biorecovery* 1 (1989): 81-126.

Bastian, R.K. “Overview on Sludge Utilization.” In *The Forest Alternative (for treatment and utilization of municipal and industrial wastes)*, edited by D.W. Cole, C.L. Henry, and W.L. Nutter, 7-25. Seattle, WA: University of Washington Press, 1986.

Berry, C.R. “Reclamation of Severely Devastated Sites With Dried Sewage Sludge in the Southeast.” In *The Forest Alternative (for treatment and utilization of municipal and industrial wastes)*, edited by D.W. Cole, C.L. Henry, and W.L. Nutter, 497-514. Seattle, WA: University of Washington Press, 1986.

Boyd, V. “Pint-sized Plants Pack a Punch in Fight Against Heavy Metals.” *Environmental Protection* (May 1996): 38-39.

Chaney, R.L. "Plant Uptake of Inorganic Waste Constituents." In *Land Treatment of Hazardous Wastes*, by J.F. Parr, P.B. Marsh, and J.M. Kla, 50-76. Park Ridge, NJ: Noyes Data Corporation, 1983.

Davey, C.B. "Sawdust Composts: Their Preparation and Effect on Plant Growth." *Soil Science Society of America Proceedings* 17 (1953): 59-60.

Haynes, J. "Applying Compost and Mulches to Control Erosion." *BioCycle* 38 (May 1997): 55-57.

Long, C. "The OG Complete Guide to Compost." *Organic Gardening* 44 (April 1997): 56-60.

MacConnell, G.S., C.G. Wells, and L. J. Metz. "Influence of Municipal Sludge on Forest Soil Mesofauna." In *The Forest Alternative (for treatment and utilization of municipal and industrial wastes)*, edited by D.W. Cole, C.L. Henry, and W.L. Nutter, 177-187. Seattle, WA: University of Washington Press, 1986.

Pietz, R.I., C.R. Carlson, Jr., J.R. Peterson, D.R. Zenz, and C. Lue-Hing. "Application of Sewage Sludge and Other Amendments to Coal Refuse Material. I. Effects on Chemical Composition." *Journal of Environmental Quality* 18 (1989): 164-169.

Sabey, B.R., R.L. Pendleton, and B.L. Webb. "Effect of Municipal Sewage Sludge Application on Growth of Two Reclamation Shrub Species in Copper Mine Spoils." *Journal of Environmental Quality* 19 (1990): 580-586.

Suppression of Plant Diseases and Pests by Compost

Achimu, P. and E. Schlösser. "Control of Plasmopara viticola With Compost Filtrates." *Mededelingen (Rijksuniversiteit te Gent. Fakulteit van de Landbouwkundige en Toegepaste Biologische Wetenschappen)* 52/2a (1991): 171-178.

Akhtar, M. and M.M. Alam. "Utilization of Waste Materials in Nematode Control: A Review." *Bioresource Technology* 45 (1993): 1-7.

Brinton, W.F., A. Trankner, and M. Droffner. "Investigations Into Liquid Compost Extracts." *BioCycle* 37 (1996): 68-70.

Campbell, R. "Microbial Interactions Leading to Biocontrol of Root Diseases—Reality or Myth?" *Aspects of Applied Biology* 22 (1989): 165-172.

Conner, D.E., J.P. Blake, and J.O. Donald. "Microbiological Safety of Composted Poultry Farm Mortalities." *American Society of Agricultural Engineers Paper No. 91-4053*, 1991.

Cook, R.J. "Making Greater Use of Introduced Microorganisms for Biological Control of Plant Pathogens." *Annual Review of Phytopathology* 31 (1993): 53-80.

Cronin, M.J., D.S. Yohalem, R.F. Harris, and J.H. Andrews. “Putative Mechanism and Dynamics of Inhibition of the Apple Scab Pathogen Venturia inaequalis by Compost Extracts.” *Soil Biology and Biochemistry* 28 (1996): 1241-1249.

Doyle, J.M. “Soil Amendments and Biological Control.” *Golf Course Management* (March 1991): 90-96.

Gilbert, R.G. and G.E. Griebel. “The Influence of Volatile Substances From Alfalfa on Verticillium dahliae in Soil.” *Phytopathology* 59 (1969): 1400-1403.

Hoitink, H.A.J. and P.C. Fahy. “Basis for the Control of Soilborne Plant Pathogens With Composts.” *Annual Review of Phytopathology* 24 (1986): 93-114.

Hoitink, H.A.J. and G.A. Kuter. “Effects of Composts in Growth Media on Soilborne Plant Pathogens.” In *The Role of Organic Matter in Modern Agriculture*, edited by Y. Chen and Y. Avnimelech, 289-306. Dordrecht, The Netherlands: Martinus Nijhoff Publishers, 1986.

Hoy, M.A. “Use of Parasites and Predators in the Biological Control of Arthropod Pests: Emerging Technologies and Challenges.” In *Entomology Serving Society: Emerging Technologies and Challenges*, edited by S.B. Vinson and R.L. Metcalf, 272-297. Lanham, MD: Entomological Society of America, 1991.

Kwok, O.C.H., P.C. Fahy, H.A.J. Hoitink, and G.A. Kuter. “Interactions Between Bacteria and *Trichoderma hamatum* in Suppression of Rhizoctonia Damping-off in Bark Compost Media.” *Phytopathology* 77 (1987): 1206-1212.

Mandelbaum, R. and Y. Hadar. “Methods for Determining Pythium Suppression in Container Media.” *Compost Science and Utilization* 5(2) (1997):15-22.

Mankau, R. “Biocontrol: Fungi as Nematode Control Agents.” *Journal of Nematology* 12 (1980): 244-252.

Muller, R. and P.S. Gooch. “Organic Amendments in Nematode Control. An Examination of the Literature.” *Nematropica* 12 (1982): 319-326.

Nelson, E.B. “The Biological Control of Turfgrass Diseases.” *Golf Course Management* (April 1992): 78-90.

Nelson, E.B. “Biological Controls.” *TurfGrass Trends* (January 1994): 1-9.

Poswal, M.A.T. and A.D. Akpa. “Current Trends in the Use of Traditional and Organic Methods for the Control of Crop Pests and Diseases in Nigeria.” *Tropical Pest Management* 37 (1991): 329-333.

Owens, L.D., R.G Gilbert, G.E. Griebel, and J.D. Menzies. “Identification of Plant Volatiles That Stimulate Microbial Respiration and Growth in Soil.” *Phytopathology* 59 (1969): 1468-1472.

Ringer, C.E., P.D. Millner, L.M. Teerlinck, and B.W. Lyman. “Suppression of Seedling Damping-off Disease in Potting Mix Containing Animal Manure Compost.” *Compost Science and Utilization* 5(2) (1997): 6-14.

Rodriguez-Kábana, R. “Organic and Inorganic Nitrogen Amendments to Soil as Nematode Suppressants.” *Journal of Nematology* 18 (1986): 129-135.

Rodriguez-Kábana, R., G. Morgan-Jones, and I. Chet. “Biological Control of Nematodes: Soil Amendments and Microbial Antagonists.” *Plant and Soil* 100 (1987): 237-247.

Serra-Wittling, C., S. Houot, and C. Alabouvette. “Increased Soil Suppressiveness to Fusarium Wilt of Flax After Addition of Municipal Solid Waste Compost.” *Soil Biology and Biochemistry* 28 (1996): 1207-1214.

Still, S.M., M.A. Dirr, and J.B. Gartner. “Phytotoxic Effects of Several Bark Extracts on Mung Bean and Cucumber Growth.” *Journal of the American Society of Horticultural Science* 101 (1976): 34-37.

Tuitert, G. and G.J. Bollen. “The Effect of Composted Vegetable, Fruit and Garden Waste on the Incidence of Soilborne Plant Diseases.” In *The Science of Composting*, edited by M. de Bertoldi, P. Bert, and P. Tiziano, 1365-1369. London: Blackie Academic and Professional, 1996.

Weller, D.M. “Biological Control of Soilborne Plant Pathogens in the Rhizosphere With Bacteria.” *Annual Review of Phytopathology* 26 (1988): 379-407.

Weltzien, H.C. “Biocontrol of Foliar Fungal Diseases With Compost Extracts.” In *Microbial Ecology of Leaves*, edited by J.H. Andrews and S.S. Hirano, 430-450. New York: Springer-Verlag, 1991.

Wilkinson, J.F. “Applying Compost to the Golf Course.” *Golf Course Management* (March 1994): 80-88.

Yohalem, D.S., R. Voland, E.V. Nordheim, R.F. Harris, and J.H. Andrews. “Sample Size Requirements to Evaluate Spore Germination Inhibition by Compost Extracts.” *Soil Biology and Biochemistry* 28 (1996): 519-525.

Compost-Enriched Phytoremediation of Contaminated Soil

Cole, M.A., L. Zhang, and X. Liu. “Remediation of Pesticide Contaminated Soil by Planting and Compost Addition.” *Compost Science and Utilization* 3(4) (1985): 20-30.

Pera, A., G. Vallini, I. Sireno, M.L. Bianchin, and M. de Bertoldi. “Effect of Organic Matter on Rhizosphere Microorganisms and Root Development of Sorghum Plants in Two Different Soils.” *Plant and Soil* 74 (1983): 3-18.

Schnoor, J.L., L.A. Licht, S.C. McCutcheon, N.L. Wolfe, and L.H. Carriera. "Phytoremediation of Organic and Nutrient Contaminants." *Environmental Science and Technology* 29 (1995): 318A-323A.

U.S. DOE. "Phytoremediation Research Needs." DOE/EM-0224. Washington, DC. U.S. Department of Energy, 1994.