Cornell Waste Management Institute

Compost Facilities: Off-Site Air Emissions and Health

http://cwmi.css.cornell.edu/compostairemissions.pdf

Summary of the literature by:

Ellen Z. Harrison
Director

July 2007

Department of Crop and Soil Sciences • 101b Rice Hall • Ithaca, NY 14853 • 607-255-1187
http://cwmi.css.cornell.edu

Summary of Articles on Compost Air Emissions and Health

This summary is has been compiled to help address concerns regarding the potential of air emissions from large-scale composting facilities to impact the health of neighbors. I have attempted to summarize and provide citations to all of the relevant journal articles and published governmental reports. Much of the available literature addresses on-site investigations that are relevant to worker health. Some of the literature on worker health is summarized here because of its relevance to neighbor impacts. However, no attempt has been made to comprehensively address worker health related to air emissions at compost facilities. A chapter in the up-dated On-Farm Composting Handbook (expected publication in 2007) will address worker health considerations. This summary does not include a comprehensive review of odor or volatile organic compound studies.

An abridged version of this literature summary that includes only those articles that directly address health impacts is available at: cwmi.css.cornell.edu/composthealth.pdf. The summaries are arranged in chronologic order of publication date, starting with the most recent. Within each year, articles are arranged alphabetically by author. The choice to place the summaries in chronologic order is based on the fact that much of the relevant literature is very recent and thus earlier articles (generally those prior to 2000) that draw conclusions based on the literature that was then available are out of date.

Please let CWMI know if there are other articles that should be included. At the end of the paper is an alphabetical list of references cited.

General Observations from the Literature

- There has been a significant contribution to the literature in the past decade, in part due to studies supported by the European Commission. (The literature summary below is organized by date of publication, with more recent publications at the beginning.)

BIOAEROSOLS

- A number of studies show that concentrations of bioaerosols downwind of outdoor composting facilities are elevated at times to distances on the order of 200-500 meters (650-1640 feet).
- Many of the bioaerosols are produced by the composting process. Data are not sufficient to determine whether the type and concentration of bioaerosols emitted are related to compost feedstock.
- Bioaerosols are particles of microbial, plant or animal origin and may be called organic dust. This can include live or dead bacteria, fungi, viruses, allergens, bacterial endotoxins (components of cell membranes of Gram-negative bacteria), antigens (molecules that can induce an immune response), toxins (toxins produced by microorganisms), mycotoxins (toxins produced by fungi), glucans (components of cell walls of many molds), pollen, plant fibers, etc.
- Microorganisms are frequently adsorbed onto dust particles.

- Many bioaerosols are known to cause symptoms and/or illness, including a wide range of adverse health effects and infection. Individuals may become sensitized to some bioaerosols through repeated exposure.
- There are no ambient or occupational exposure limits for bioaerosols in the U.S.
- Validated standard methods are not yet available for measuring the various bioaerosols.
- All monitoring methods underestimate bioaerosol concentrations. Use of culture techniques will underestimate potential health risks since non-viable, non-culturable microorganisms as well as non-living constituents can contribute to health risks. Direct spore counts can provide a somewhat better estimate of exposure for irritation and allergic reactions, but cannot determine viability and thus potential for infection; but this method still underestimates exposure to particulates and pieces of bacteria (endotoxin), spores and fungal hyphae which can also produce irritation, allergy, and toxic reactions. Also, direct spore counts cannot distinguish between some species (such as *Penicillium* and *Aspergillus*), making exposure indeterminant. DNA analysis methods using PCR technology are being developed for more and more species, but are still limited in what types can be identified.
- Variation in exposure to bioaerosols from composting facilities is high even over short time periods. Intermittent releases and changes in wind complicate air monitoring since sampling other than for short time intervals can be difficult.
- The relative abundance of *Aspergillis fumigatus* and other microbes varies seasonally in air emissions from composting facilities. *A. fumigatus* is ubiquitous in both outdoor and indoor (particularly where there are pets) air.
- Measuring *A. fumigatus* is not a good indicator for other bioaerosols.
- Concentrations of bioaerosols in enclosed composting facilities are significantly elevated.

HEALTH

- An association was found in residents between distance to an outdoor composting facility and respiratory symptoms and general health complaints, but not allergies or infectious disease.
- Self-reported symptoms were not correlated with *A. fumigatus* levels in the air in the vicinity of a large open-air yard waste composting facility.
- Compost workers show a response to elevated exposure to bioaerosols despite the fact that there is a "healthy worker" effect (compost workers' general health apart from potential compost-related illness is better than average people). Acute and chronic respiratory health effects, mucosal membrane irritation, skin diseases and inflammatory markers were elevated in workers.
- Short-term exposure to air in an enclosed composting facility resulted in measurable systemic changes in healthy subjects.
- Occupational exposure to bioaerosols may be reduced through a combination of engineering controls, work practices (and other administrative controls), and personal protective equipment.

COMPOST MANAGEMENT

- Agitation of the compost (such as turning and screening) produces emissions. Minimizing agitation, application of water to minimize dust, monitoring wind to avoid agitation when winds are likely to blow towards neighbors can help minimize impacts.
- Frequency of turning (unless at least daily) has little impact on keeping piles aerated and increased turning can increase bulk density and thus reduce air flow through the compost pile.
- Good management of composting can help minimize odor impacts, however, odors are generated even at well-managed compost facilities. Compounds causing odors are not generally present off-site at concentrations high enough to cause illness, however excessive odors can result in symptoms such as nausea.
- Odors are minimized when there is adequate oxygen and oxygen is best controlled through ensuring free air space by using amendments like wood chips that improve porosity.
- A blanket of finished compost on top of unfinished piles can reduce odor and VOC (volatile organic compound) emissions. There are no data to demonstrate whether it will reduce bioaerosol emissions.
- Leachate is particularly odorous thus measures to prevent leachate from collecting at compost sites are important.
- Compost is most odorous and more VOCs are emitted in first several weeks of material handling.
- There is the potential to move odors off-site by transport of odorous material in tire treads.
- Wood chips release VOCs during composting. The chipping operation itself also releases VOCs.

Literature Summary

- Bunger, J., B. Schappler-Scheele, R. Hilgers, and E. Hallier. 2006. A 5-Year Follow-Up Study on Respiratory Disorders and Lung Function in Workers Exposed to Organic Dust from Composting Plants. International Archives of Occupational and Environmental Health. Online: http://www.springerlink.com/content/82u23r2371414873/fulltext.pdf

Conclusion: exposure to organic dust at composting workplaces is associated with adverse acute and chronic respiratory health effects. Compost workers were compared to controls at 41 German compost facilities (mixed household biowaste plus yard wastes). Exposure measurements revealed high concentrations of fungi and actinomycetes. Compost workers report significantly higher prevalence of mucosal membrane irritation of eyes and upper airways as well as more conjunctivitis. A significant decline in forced vital capacity was measured. Results differ from workers exposed to organic dust in other facilities, maybe due to thermotolerant fungi and bacteria in compost plants.

- Muller, T., R. A. Jorres, E. M. Scharrer, H. Hessel, D. Nowak, and K. Radon. 2006. Acute Blood Neutrophilia Induced by Short-Term Compost Dust Exposure in Previously Unexposed Healthy Individuals. International Archives of Occupational and Environmental Health. 79:477-482.

Conclusion: Short-term exposure of healthy young subjects to organic dust at composting facilities had mild but measurable effect in eliciting acute systemic alterations. 17 healthy subjects not working with wastes were exposed to a composting facility for 2 hrs doing moderate exercise. Changes in white blood cell counts, an increase in neutrophils and decrease in eosinophils was measured.

- Pagans, E., X. Font, and A. Sanchez. 2006. Emission of Volatile Organic Compounds From Composting of Different Solid Wastes: Abatement by Biofiltration. Journal of Hazardous Materials. B131:179-186.

VOC emissions from lab-scale composting of various organic wastes showed maximum emissions early in the composting process. Emissions were run through a biofilter that reduced levels to ~50.

- Spencer, R. and C. M. Alix. 2006. Dust Management, Mitigation at Composting Facilities. BioCycle. 47(3):55

"Composting operations are industrial facilities, like factories. As such, the same reasoning and concepts of industrial hygiene that apply to any other type of factory also apply to compost factories."

Controlling dust is important. It is a challenge to get moisture content correct. Optimal moisture during decomposition is 60-65%. For screening it is about 40%. If it gets too dry, dust is created. Management includes keeping traffic areas clean, use of water spray trucks.

Odors can travel with the dust. Dust can clog drainage systems and give odor and BOD to the leachate. Dust can be a fire hazard at the facility.

Dust control measures include: pave roads; keep roads, areas and equipment clean; dampen loads; enclose and ventilate potentially dusty process areas such as tipping floors, picking lines and storage and packaging areas; provide masks for workers; consider spraying;

- Wouters, I. M., S. Spaan, J. Douwes, G. Doekes, and D. Heederik. 2006. Overview of Personal Occupational Exposure Levels to Inhalable Dust, Endotoxin, $\beta(1\rightarrow3)$-Glucan and Fungal Extracellular Polysaccharides in the Waste Management Chain. Annuals of Occupational Hygiene. 50(1):39-53.

Monitoring of worker exposure in one indoor facility composting household waste as well as a second study at 13 facilities (3 residential organic wastes - indoors; 6 green waste - outdoors; 4 mixed residential organic wastes and green waste - indoors). Caution is required in comparing different studies due to method differences. Endotoxin and dust levels at residential organic waste and mixed composting facilities were higher than green waste and endotoxins at such facilities often exceed Dutch occupational standards (but not in green waste). Highest exposure occurs where waste is disturbed. Within worker variation in exposure was generally higher than between workers. Variation in bioaerosol composition of dust was high.

- Goldstein, J. and N. Goldstein. 2005. Controlling Odors at Composting Facilities. BioCycle. 46(5):22

Findings based on operator experience showed that insufficient carbon and insufficient turning caused leachate and odor problems. Leachate treatment in artificial wetlands and improved pad reduced leachate issues. Pad improvements eliminated ruts where leachate collected. Odor monitoring can help and there are devices available.

Managing feedstocks so that they are incorporated into a mix with appropriate moisture content; appropriate carbon:nitrogen ratio; sufficient coarse bulking material to maintain aerobic conditions. pH adjustment to below 7.5 may help keep ammonia down in nitrogenous feedstocks. Adding alum, gypsum or sulfur can lower pH. Cover conveyor belts and install water misters at drop points. Use static negative aeration (sucking) system and capture air and run through biofilter. See also book "Odor Management at Composting Facilities" by BioCycle.

- Schlegelmilch, M., J. Streese, W. Biedermann, T. Herold, and R. Stegmann. 2005. Odour Control at Biowaste Composting Facilities. Waste Management. 25:917-927

Main source of odorous emissions is during movement of materials. Leachate can add to odors.

Minimize odors by avoiding anaerobic conditions. Storage of feedstocks can be odor producing. Composting under semi-permeable cover may help [but this would not be relevant during movement of materials]. Maximum odors during first several weeks of composting.

- Department for Environmental Food and Rural Affairs. 2004. Review of the Environmental and Health Effects of Waste Management. Online. Available: http://www.defra.gov.uk/ENVIRONMENT/waste/research/health/index.htm.

This document provides a broad review of waste management options and their health and environmental impacts. The authors were unable to estimate the potential health effects of air emissions from composting due to a lack of information. The need for further research on the emissions and health impacts of composting is recognized.

- Prasad, M., P. van der Werf, and A. Brinkmann. 2004. Bioaerosols and Composting - A Literature Evaluation. Composting Association of Ireland TEO.

This literature review summarizes the data on bioaerosols from various studies. A setback of 200 m is recommended since "generally background concentrations are achieved within a few hundred meters."

- Heroux, M., T. Page, C. Gelinas, and C. Guy. 2004. Evaluating Odour Impacts From a Landfilling and Composting Site: Involving Citizens in the Monitoring. Water Science and Technology. 50(4):131-137

Odors were significant within 500 m of yard waste composting facility.

- Herr, C. E. W., A. zur Nieden, H. Seitz, S. Harpel, D. Stinner, N. I. Stilianakis, and T. F. Eikmann. 2004. Bioaerosols in Outdoor air - Statement of Environmental Medical Assessment Criteria on the Basis of an Epidemiological Cross Sectional Study. Gefahrstoffe Reinhaltung Der Luft. 64(4):143-152.

Total bioaerosols (total bacteria, molds and thermophilic actinomycetes) were found at $>10^5$ CFU/m^3 in outdoor air in the vicinity of an outdoor composting facility, dropping to background concentrations within 550 m. There was an association between irritative respiratory symptoms and general health complaints and distance to the site. There was no higher prevalence of reported allergies or infectious diseases. Individual odor annoyance was not associated with symptoms.

- Herr, C. E. W., A. zur Nieden, N. I. Stilianakis, and T. F. Eikmann. 2004. Health Effects Associated With Exposure to Residential Organic Dust. American Journal of Industrial Medicine. 46:381-385.

Significantly higher than background concentrations of thermophilic actinomycetes, total bacteria and molds were measured in air down wind 200 m from an outdoor composting site, dropping to near background within 300 m. These levels are similar to occupational composting exposures. A physician-administered survey found airway symptoms but not odor annoyance were observed in residents in highest exposure (150-200 m downwind) vs further away (400-500 m). An association was demonstrated between residential bioaerosol pollution and irritative airway complaints as well as excessive fatigue and shivering (which symptoms are reported at workplaces handling such materials). Residents reporting odors did not "overreport" health disturbances.

- Rosenfeld, P., M. Grey, and P. Sellew. 2004. Measurement of Biosolids Compost Odor Emissions From a Windrow, Static Pile, and Biofilter. Water Environment Research. 76(4):310-315.

Biosolids/greenwaste/stable bedding composted in outdoor windrow and aerated static pile. Emissions from 2 facilities were compared and odor removal with 2-phase biofilter was determined. Identified chemicals responsible for odors: ammonia, dimethyl disulfide, carbon disulfide, formic acid, acetic acid and sulfur dioxide (=carbonyl sulfide). Aerated static pile reduced ammonia (72%), formic acid (57%) and acetic acid (11%) and others were below detection. Aeration followed by biofiltration reduced odor 98%. However, after biofilter, there were still odors exceeding detection threshold for ammonia (42x threshold), dimethyl disulfide (9600x), carbon disulfide (18x), and acetic acid (3x).

- Muller, T., R. Thissen, S. Braun, W. Dott, and G. Fischer. 2004. (M)VOC and Composting Facilities. Part 2: (M)VOC Dispersal in the Environment. Environmental Science and Pollution Research - International. 11(3):152-157.

Microbially-generated odorous volatile organic compounds (MVOCs) were measured in the vicinity of two enclosed facilities composting a mixture of plant waste and sewage sludge in Germany. MVOCs were not found in background air, but were detected downwind. Terpenes were the dominant compound and were detected to a distance of 800 m (the farthest point measured) at 10^3 nanograms/m^3. Concentrations varied over 3 orders of magnitude in the 8 sampling events. At one facility, concentrations were higher at a greater distance, likely due to air circulation patterns. The health implications are unknown. Concentrations were lower than those associated with toxicity for those chemicals for which there are data, but the impacts of long-term exposure are unknown. The odors associated with the emissions may cause symptoms.

- Rosenfeld, P. E., M. A. Grey, and I. H. Suffet. 2004. Compost Odor Control Using High Carbon Wood Ash. Water Science and Technology. 49(9):171-178.

VOCs measured at the surface of green waste windrows in Sacramento, CA contained concentrations greatly exceeding odor thresholds for a number of compounds, particularly on day 1 vs. day 7. Incorporation of wood ash reduced odors.

- Rosenfeld, P. E. and I. H. Suffet. 2004. Understanding Odorants Associated With Compost, Biomass Facilities, and the Land Application of Biosolids. Water Science and Technology. 49(9):193-199.

The highest emissions from a green waste windrow compost facility in Sacramento, CA occurred early in process and during agitation. VOCs were measured at the surface of the windrow. Biosolids compost releases sulfur and nitrogen compounds while green waste releases volatile fatty acid, ketones, terpenes and aldehydes. Aerobic composting of green wastes produces aldehydes, alcohols, ketones, volatile fatty acids, terpenes and ammonia compounds that are associated with compost odors. Turning releases odorants.

- Smyth, B. and R. Rynk. 2004. Can Composting BMPs Reduce Air Emissions? BioCycle. 45(3):46-50.

This preliminary study was performed in response to concerns about California air quality and was not focused on neighbor impacts. Air monitoring from 4 experimental windrow composting piles showed that yard wastes did not emit ammonia and that VOC emissions were inversely correlated with C:N ratio (higher N resulting in more VOCs). Piles turned several times a week had higher emissions than unturned piles in the first several weeks.

- Douwes, J., P. Thorne, N. Pearce, and D. Heederik. 2003. Bioaerosol Health Effects and Exposure Assessment: Progress and Prospects. Annals of Occupational Hygiene. 47(3):187-200.

This is a review article. Risk assessment for bioaerosols is "seriously hampered by the lack of valid quantitative exposure assessment methods. Traditional culture methods to quantify microbial exposures have proven to be of limited use." "…many biological agents that may cause health effects are currently not identified. For instance, sewage treatment workers have an increased risk of developing a wide range of symptoms including respiratory, gastrointestinal and neurological symptoms, whereas causal agents have not been identified."

Culture methods for measurement of bioaerosols is more qualitative than quantitative. It has poor reproducibility, does not measure some organisms and does not measure non-living constituents. Non-culture methods rely on microscopes or flow cytometry to identify and count.

In general, exposure to bioaerosols can be associated with wide range of adverse health effects (including contagious diseases, acute toxic effects, allergies and cancer as well as possibly pre-term births or late abortions and dermatitis). Workers in waste industry are often exposed to very high levels of microorganisms and several studies indicate high prevalence of respiratory symptoms and airway inflammation.

Diseases and symptoms associated with various bioaerosol components are described.

- Gage, J. 2003. Checklist for Odor Management at Compost Facilities. BioCycle. Vol. 44:42-47.

Odor generation is affected by oxygen demand of decomposer organisms in the compost; rate of degradation; type of organic compounds and conditions that influence process chemistry. Start up is the biggest challenge (first 2 weeks). There is high oxygen demand at that time which is affected by temperature. If pile gets too hot, mixing can help cool it through evaporative cooling, however that will also cause loss of a lot of water.
Optimizing pile size can speed the process.

Checklist:

1. Optimize process
Especially for the first 2 weeks keep the piles small (<4 feet tall x 6 ft wide) to promote air movement
Maintain adequate porosity. Deep woodchip base can help air circulation into pile
Mix feedstocks well and use diverse mix
Add water in light and frequent applications to maintain adequate moisture
Keep pH moderate (under 8) by adding acidification agents

2. Material handling
Handle feedstocks promptly
Blend in bulking agents
Mist materials
Cover conveyors
Keep site clean, no standing water
Cover piles with moist woody materials

3. Recognize different stages of composting
Days 1-7 or 14 – keep below 50^0 C, >50% moisture
Next 3-18 days – $55\text{-}65^0$ C. Less air, larger windrows
Next 20 days – curing

- Herr, C. E. W., A. Zur Nieden, R. H. Bodeker, U. Gieler, and T. F. Eikmann. 2003. Ranking and Frequency of Somatic Symptoms in Residents Near Composting Sites With odor Annoyance. International Journal of Hygiene and Environmental Health. 206:61-64.

This brief paper reports results of an epidemiologic study of people living in the vicinity of three composting plants. Residents living near one of the sites at which concentrations of microorganisms were high experienced increased symptoms relative to the control population. Nausea was associated with strong odors.

- Sanchez-Monedero, M. A., E. I. Stentiford, and C. Mondini. 2003. Biofiltration at Composting Facilities: Effectiveness for Bioaerosol Control. Environmental Science and Technology. 37:4299-4303.

Biofilters at 7 composting facilities reduced concentrations of airborne *Aspergillus fumigatus* on average by 90% while concentrations of mesophilic bacteria were only reduced by 39%. The size of the fungal spores vs the smaller size of the bacteria may be responsible for the different capture rates.

- Buckner, S. C. 2002. Controlling Odors During Grass Composting. BioCycle. 43(9):42-47.

A large municipal yard waste outdoor windrow composting facility on Long Island in NY conducted experiments to reduce odors resulting from large quantities of grass clippings (~15,000 tons/yr). Various attributes of grass clippings make them prone to becoming anaerobic and odorous. Two bulking materials (wood chips and leaves) were combined at two rates (1:1 and 2:1) and different turning frequencies (1/wk and 6/wk) were tested. All piles had similar odor intensity at the start, but odor from the wood chip piles, particularly the 2:1 wood chip to grass mix, declined more rapidly. Frequent turning resulted in more rapid degradation and lower oxygen. Oxygen concentration was inversely correlated with odor, with 10% or higher oxygen concentrations necessary to maintain low odor levels. Oxygen in the leaf/grass piles was lower than the woodchip/grass piles. However, even with >10% oxygen, piles containing only grass were still odorous. There was no correlation between odor and temperature.

- Michel Jr, F. C. 2002. Effects of Turning and Feedstocks on Yard Trimmings Composting. BioCycle. 43(9):46.

Turning frequency of yard waste compost windrows did not improve aeration, had little impact on temperatures and increased bulk density. Turning weekly or even monthly is recommended unless there is a need to stabilize compost quickly, in which case daily turning may speed up the process by 20%.

- Gilbert, E. J., A. Kelsey, J. D. Karnon, J. R. M. Swan, and B. Crook. 2002. Preliminary Results of Monitoring the Release of Bioaerosols from Composting Facilities in the UK: Interpretation, Modeling and Appraisal of Mitigation Measures. 2002 International Symposium on Composting and Compost Utilization, Columbus, Ohio.

Bioaerosols (culturable mesophilic bacteria and *Aspergillus fumigatus*) monitored several times downwind of two composting facilities (one 12,000 tons/yr of green waste, one 5000 tons/yr of green waste plus kitchen waste) in the UK were elevated, but decreased approximately exponentially with distance from the source, reaching background concentrations within about 200 m. At a distance of 25-100 m, a ten-fold reduction from the concentration at the source was calculated.

- Swan, J. R. M., B. Crook, and E. J. Gilbert. 2002. Microbial Emissions from Composting Sites. Pages 73-101 *in* Issues in Environmental Science and Technology. Vol. 18. R. E. Hester and R. M. Harrison, eds. Royal Society of Chemistry.

This book chapter provides an excellent summary of the literature.

- Browne, M. L., C. L. Ju, G. M. Recer, L. R. Kallenbach, J. M. Melius, and E. G. Horn. 2001. A Prospective Study of Health Symptoms and *Aspergillus fumigatus* Spore Counts Near a Grass and Leaf Composting Facility. Compost Science and Utilization. 9(3):241-249.

Aspergillis fumigatus spore concentrations are higher in vicinity of 40 acre yard waste composting site than background. Participant diaries showed no correlation between symptoms and *A. fumigatus* concentrations. However there are caveats: large short term variations in concentrations of *A. fumigatus* were measured and the spore counts used were averages and were taken at sampling locations not specific to personal exposures.

- Recer, G. M., M. L. Browne, E. G. Horn, K. M. Hill, and W. F. Boehler. 2001. Ambient Air Levels of *Aspergillus fumigatus* and Thermophilic Actinomycetes in a Residential Neighborhood Near a Yard-Waste Composting Facility. Aerobiologia. 17(2):99-108.

Concentrations of airborne *Aspergillus fumigatus* and thermophilic actinomycete were significantly higher at distances of at least as far 500 m downwind of a large yard waste composting facility. At the composting facility, levels exceeded background means by roughly 20-fold. Concentrations varied widely, particularly downwind of the facility. They were generally lower in the winter. At the neighborhood monitoring site (540 m from the compost facility) concentrations were higher when the wind direction blew from the facility towards the neighborhood. These findings "are consistent with a direct influence of compost-pile spore emissions on IFC (the Islip compost facility) and study neighborhood."

- Wheeler, P. A., I. Stewart, P. Dumitrean, and B. Donavan. 2001. Health Effects of Composting - A Study of Three Compost Sites and Review of Past Data, Technical Report P1-315/TR. Pages 111. UK Environment Agency.

This literature review and report on monitoring of emissions from 3 composting plants (2 green waste turned windrow facilities and one mixed waste in-vessel facility) says that "Composting activities do emit bioaerosols at levels which can pose a hazard to susceptible members of the public. However, the precise risk is impossible to quantify due to the lack of defined dose-response relationships." A buffer zone of 250 m is suggested. Concentrations for total bacteria of 1000 cfu/m^3, 1000 cfu/m^3 for total fungi, 300 cfu/m^3 for gram-negative bacteria and 250 μg/m^3 for inhalable dust are suggested as conservative (low) protective values. These concentrations are generally exceeded at composting sites (10^5-10^6 cfu/m^3 of bacteria and gram negative bacteria and 10^3-10^4 cfu/m^3 of fungi were measured), suggesting the value of respiratory protection for workers. Under most conditions concentrations decline to these levels within a distance of 250 m from compost facilities. Emissions measured on-site fell within the range of 10^3-10^7 fungi and bacteria during compost agitation as observed. Due to clumping of bacteria and overloading of Andersen samplers, bacterial concentrations measured using a filter method were approximately 10 times higher than those measured with an Andersen sampler. While generally concentrations declined with increasing distance, in some cases concentrations peaked a short distance from the operation. The significant levels of biological agents in clothing of compost workers suggests that families may be exposed if workers take clothes home.

- UK Environment Agency. 2001. Agency Position on Composting and Health Effects (Bristol). Pages 6.

"There will be a presumption against permitting of any new composting process [or any modification to an existing process] where the boundary of the facility is within 250 m of a workplace or the boundary of a dwelling, unless the application is accompanied by a site-specific risk assessment..." Measures that may allow operations closer to neighbors will be investigated. Existing sites that are closer to neighbors will be assessed.

- Hryhorczuk, D., L. Curtis, P. Scheff, J. Chung, M. Rizzo, C. Lewis, N. Keys, and M. Moomey. 2001. Bioaerosol Emissions from a Suburban Yard Waste Composting Facility. Annals of Agricultural and Environmental Medicine. 8:177-185.

This paper includes a summary of literature data on bioaerosols and compost facilities. This study sampled for viable fungi and bacteria once each morning for 10 days from Sept-Nov (and sometimes took a second afternoon set of samples) at an outdoor green waste compost facility. 8 locations ranging from 10 m from pile to ~300 m downwind were tested. Sampling included 24 hr spore sampling as well as a personal sampler on a worker. It is wooded off-site, with a berm 3 m tall in one direction. Compost activity was intense on 5 days. On-site concentrations of total spores, Aspergillus/Penicillium spores, total bacteria, gram-negative and gram-positive bacteria, actinomycetes, total particulates, endotoxins, B-1,3 glucans were higher at the yard waste composting facility than background. Peak exposures were high enough to warrant use of respirators by workers during activities that generate dust. Bacteria and fungi were elevated in the samples 10 m (33 feet) from the compost rows and fungi were elevated at the fence line (75 feet from the nearest pile), but there was not a clear increase at more distant sample locations.

- Bunger, J., M. Antlauf-Lammers, T. Schulz, G. Westphal, M. Muller, P. Ruhnau, and E. Hallier. 2000. Health Complaints and Immunological Markers of Exposure to Bioaerosols Among Biowaste Collectors and Compost Workers. Occupational and Environmental Medicine. 57:458-464.

Compost workers had significantly more symptoms and diseases of the airways and skin than control subjects. Some workers quit due to airway complaints leading possibly to underestimation of health effects. Increased anti-body concentrations against fungi and actinomycetes were found in compost workers. There was an association between the diseases and increased antibody concentrations in compost workers. A “healthy worker” effect is indicated by the under representation of atopic (allergic) diseases among compost workers.

- Douwes, J., I. Wouters, H. Dubbeld, L. v. Zwieten, P. Steerenberg, G. Doekes, and D. Heederik. 2000. Upper Airway Inflammation Assessed by Nasal Lavage in Compost Workers: A Relation With Bio-Aerosol Exposure. American Journal of Industrial Medicine. 37(5):459-468.

“Compost workers are at risk of developing acute and possibly chronic inflammatory responses in the upper airways…” Workers in compost plant that stored and processed source-separated food and yard waste indoors were studied using nasal lavage (NAL) (in which fluid is inserted in the nose and then removed and analyzed for various markers). The study included two time periods, one before and one after process improvements were made to try and decrease exposure to bioaerosols in the facility. Compared with controls, before the facility improvements the workers had higher indicators inflammatory markers even on Monday morning before work. Comparing pre and post-shift, workers showed an increase in markers.

- Peterson, M. K., D. L. Johnson, and R. C. Pleus. 2000. Characterization of Emissions From Two Yard-Waste Composting Facilities. Intertox, Inc, Seattle, WA.

VOCs, reduced sulfur compounds and ammonia emissions were measured up and down wind of two yard waste composting facilities. Duplicate grab samples were collected once during evening hours in September (a time when odor complaints were reported). The few samples preclude statistical analysis. Four compounds (2-butanone, 4-methyl-2-pentanone, m, p-xylenes, carbon disulfide) were detected at slightly higher concentrations down wind. Ammonia was much higher down wind and exceeded the USEPA benchmark at the downwind location for one site.

- Curtis, L., M. Ross, V. Persky, R. Wadden, V. Ramakrishnan, and D. Hryhorczuk. 1999. Characterization of Bioaerosol Emissions from a Suburban Yard Waste Composting Facility. Pages 254-257 *in* Bioaerosols, Fungi and Mycotoxins: Health Effects, Assessment, Prevention and Control. E. Johaning, ed, Sarasota Springs, NY.

Monitoring bioaerosols on and off-site of a yard waste composting facility once in the morning for 10 days between September and November in the vicinity of Chicago, IL showed higher airborne bacterial and fungal concentrations immediately downwind. Tremendous variation in concentrations was measured (several orders of magnitude) at each location. “Compost activity significantly increased downwind concentrations of bacteria both on-site and off-site.”

- Fischer, G., T. Muller, R. Ostrowski, and W. Dott. 1999. Mycotoxins of *Aspergilius fumigatus* in Pure Culture and in Native Bioaerosols from Compost Facilities. Chemosphere. 38(8):1745-1755.

Extracts of dust and bioaerosols from the air of one of two indoor composting plants contained low concentrations of some mycotoxins produced by *A. fumigatus*. The number of *A. fumigatus* was not correlated with amount of dust in the air and the concentration of mycotoxins is related to *A. fumigatus* and not to dust.

- Neef, A., A. Albrecht, F. Tilkes, S. Harpel, C. Herr, K. Liebl, T. Eikmann, and P. Kampfer. 1999. Measuring the Spread of Airborne Microorganisms in the Area of Composting. Schriftenr Ver Wasser Boden Lufthyg. 104:655-664.

Emission concentrations of culturable microorganisms were determined in the vicinity of three open or partly encapsulated composting facilities. Sampling was performed during “worst case” situations which should promote aerial transport of emissions. Generally, concentrations decreased significantly with increasing distances from the plant at all three locations. At one plant 10^6 CFU/m^3 of thermophilic actinomycetes were found at a distance of 200 m. Elevated concentrations were measured even in distances greater than 500 m. Concentrations could vary ten-fold within one hour.

- Folmsbee, M. and K. A. Strevett. 1999. Bioaerosol Concentration at an Outdoor Composting Center. Journal of Air and Waste Management Association. 49:554-561.

Monitoring of microorganisms in the air (bacteria, fungi and actinomycetes) was conducted around Norman, OK outdoor windrow compost facility. The downwind monitoring site was ~10 m from the compost windrow. “Sampling was preferentially performed during the absence of activity” so it was not sampled during turning or material movement. Results showed 10-fold higher microorganisms down wind.

- Eduard, W. and D. Heederik. 1998. Methods for quantitative assessment of airborne levels of noninfectious microorganisms in highly contaminated work environments. American Industrial Hygiene Association Journal. 59(2):113-127.

This article reviews sampling issues for bioaerosols and discusses various sampling instruments.

Workers in indoor compost facilities are exposed to substantially higher levels of colony forming units and total microorganisms than generally found in indoor air. There are not standards for occupational exposure to microorganisms. Measurement is not straightforward and different methods may measure different entities. There is not a standard method for analysis of endotoxins, but due to inhibition by other constituents in the dust, levels can be underestimated. “Culture-based methods are poor surrogate methods for assessment of nonculturable microorganisms and also have poor precision… At present microscopic methods seem most suitable for assessment of exposure to microorganisms in the workplace.”

- Fischer, J. L., T. Beffa, P.-F. Lyon, and M. Aragno. 1998. *Aspergillus fumigatus* in Windrow Composting: Effect of Turning Frequency. Waste Management and Research. 16(4):320-329.

Experiments on the impact of turning frequency in open windrow piles of garden and kitchen waste using a windrow turning machine were conducted over 7 weeks in autumn in Switzerland. Pile temperatures profiles were recorded and *Aspirgillus fumigatus* (AF) concentrations were measured in the compost and in the air at nose height just downwind from the turning machine and at 2, 5 and 10 m distance. More frequent (daily vs. weekly) turning raised temperatures more quickly and reduced AF concentrations at the pile surface. AF in the air 5 m behind the turning machine was 10 to 100 times lower in the frequently turned pile. A pile turned only once a month showed elevated AF concentrations in the compost and the air and elevated concentrations persisted for the 16 week investigation, peaking at 8 weeks. Concentrations of AF 10 m downwind were 100-1000 lower than just behind the machine and outside of the site perimeter concentrations were not generally higher than background. Elevated temperatures are suggested as the primary factor in AF reduction.

- Fischer, G., R. Schwalbe, R. Ostrowski, and W. Dott. 1998. Airborne Fungi and their Secondary Metabolites in Working Places in a Compost Facility. Mycoses. 41:383-388.

Total colony-forming units of airborne fungi were found at 10^6 to $10^7/m^3$ in air in an indoor compost facility and in the loading area. Species composition varied over the year, with *Aspergillus fumigatus* dominant in the winter and spring (~10^6) but *Paecilomyces variotii* (also capable of causing infections) was dominant in summer (~10^6) while *A. fumigatus* was lower (10^4-10^5). Thus “it is not sufficient to define *A. fumigatus* exclusively as an indicator organism for exposure to biowaste-deriving fungi.” Different fungal species can produce different toxic metabolites and have different toxicological health impacts.

- Tolvanen, O. K., K. I. Hanninen, A. Veijanen, and K. Villberg. 1998. Occupational Hygiene in Biowaste Composting. Waste Management & Research. 16(6):525-540.

Biowaste (organic waste) composting open windrows on an asphalt pad in Helsinki, Finland were monitored for VOCs and bioaerosols. A one hectare (2.47 acres) site in 1993-4 increased to 2 hectares in 1995. The original mix was 2/3 wood chips and windrows were 3 m high in 1993-4. Turning was changed from 1/3weeks to 1/week. Due to neighbor issues, the operation eventually changed to drum composting and emissions were reduced.

Sampling was conducted for VOCs just above and in holes in the compost piles. Strong odors were observed during first several weeks when the piles were turned. Leachate was particularly odorous. Microorganism and dust samples were taken about 20 m from the windrows. For all downwind samples, microbe concentrations were higher in summer than winter and exceeded recommended thresholds during agitation of the piles. Less tall windrows and more frequent turning and higher proportion of wood chips helped reduce odors, but proved too expensive.

▪ Danneberg, G., E. Grüneklee, M. Seitz, J. Hartung, and A. J. Driesel. 1997. Microbial and Endotoxin Emissions in the Neighborhood of a Composting Plant. *in* Waste Collection and Recycling - Bioaerosol Exposure and Health Problems. Annals of Agricultural and Environmental Medicine, Denmark.

Total bacteria, *Aspirgillus fumigatus* and endotoxins were measured at one time in air in the vicinity of a compost facility in Germany. Timing of sampling relative to disturbance of materials and to wind intensity is not specified. Endotoxins, total bacteria and AF were somewhat elevated at the downwind (150 m) location, but were 100 times less than concentrations near the rotating sieve. Other molds were not different in control vs. downwind measurements. Modeling suggests that at a distance of 500 m, concentrations are probably within background levels.

▪ Epstein, E. 1997. Bioaerosols. Pages 247-299 *in* The Science of Composting. Technomic Publishing, Lancaster, PA.

This book chapter reviews bioaerosol information.

▪ Ivens, U. I., J. Hansen, N. O. Breum, N. Ebbehoj, M. Nielsen, O. M. Poulsen, H. Wurtz, and T. Skov. 1997. Diarrhoea Among Waste Collectors Associated With Bioaerosol Exposure. Annals of Agricultural and Environmental Medicine. 4:63-68.

A survey of Danish waste collectors demonstrated an association between the level of exposure of workers to fungal spores and self-reported diarrhoea. However, the group with high exposure to either total fungi or total microorganisms reported fewer symptoms compared to the less exposed group.

▪ Marth, E., F. F. Reinthaler, K. Schaffler, S. Jelovcan, S. Haselbacher, U. Eibel, and B. Kleinhappl. 1997. Occupational Health Risks to Employees of Waste Treatment Facililties. Annals of Agricultural and Environmental Medicine. 4:143-147.

Several measures of allergy, inflammation and lung function were measured in 117 workers at 2 composting and 3 waste sorting facilities and compared with a control group. Although elevated IgE was detected, no statistically significant increase in allergic diseases was found. Eye and mucous membrane irritation, coughing and decreased lung function were measured.

▪ Reinthaler, F. F., E. Marth, U. Eibel, U. Enayat, O. Feenstra, H. Friedl, M. Kock, F. P. Pichler-Semmelrock, G. Pridnig, and R. Schlacher. 1997. The Assessment of Airborne Microorganisms in Large-Scale Composting Facilities and their Immediate Surroundings. Aerobiologia. 13:167-175.

Airborne microorganisms (culturable bacteria, gram negative bacteria, moulds and yeasts) in the vicinity of 3 systems composting primarily yard, agricultural and forest organic wastes were measured every several weeks for brief intervals in the mid-day hours. During agitation of the materials, concentrations measured inside the facilities at times exceeded the limits of quantification (5 x 10^5 CFU/m^3), No differences were found in the distribution of bacteria and moulds in the different size dust fractions. The majority of particles were in the respirable fraction. Concentrations downwind of the one open air facility were higher in summer than winter and varied greatly depending on climatic influences and site operation.

- van Tongeren, M., L. van Amelsvoort, and D. Heederik. 1997. Exposure to Organic Dusts, Endotoxins, and Microorganisms in the Municipal Waste Industry. International Journal of Occupational and Environmental Health. 3:30-36.

Sampling was conducted both at and upwind of a compost screening plant (and other waste facilities) in Sept. and March for 3 days for dusts and endotoxins (personal worker exposure) and for microorganisms in the air (Anderson sampler). Results were highly variable between different days and different workers. "High levels of exposure to organic dusts occurred in the compost-screening plant (arithmetic mean: 9.7 mg/m^3) with 6-8 hr exposure of 55.1 mg/m^3. Endotoxin exposure averaged 19.6 ng/m^3 and ranged from 0.2-186.2. "Very high" levels of total airborne fungi were found. (9.6 x 10^4 cfu/m^3 arithmetic mean). "Total airborne bacteria concentrations were also very high" (arithmetic mean 2.81 x 10^5cfu/m^3). Guidelines for airborne fungi are 1 x 10^4 cfu/m^3 (Amer. Conference of Gov. Industrial Hygienists).

- Lacey, J., P. A. M. Williamson, and B. Crook, eds. 1996. Microbial Emissions From Composts and Associated Risks - Trials and Tribulations of an Occupational Aerobiologist. CRC Press, Boca Raton, FL.

Air in several locations in a pilot plant sorting and composting mixed waste was sampled using a variety of methods. Limitations of the different methods included undercounting due to overloaded plates, changes in species both overtime and with two different runs of the pilot plant, higher counts using personal samplers (sampling devices worn by workers) versus ambient samplers and difficulty in identifying specific species were noted. Concentrations of gram negative bacteria and dust exceeded recommended limits.

- Hentz Jr, L. H., W. E. Toffey, and C. E. Schmidt. 1996. Understanding the Synergy Between Composting and Air Emissions. BioCycle. 37(3):67-75.

Emissions of VOCs, odors and dimethyl disulfide were correlated with temperatures in a sewage biosolids static forced air system in Philadelphia, PA. Improved airflow (resulting in cooler temperatures) and biofilter management resulted in reduced VOC and odor emissions. When poorly performing, the biofilter was a source of VOCs and odors.

- Cobb, N., P. s. Sullivan, and R. A. Etzel. 1995. Pilot Study of Health Complaints Associated with Commercial Processing of Mushroom Compost in Southeastern Pennsylvania. Journal of Agromedicine. 22(2):13-25.

In response to residents' complaints, a symptom questionnaire was administered to 100 residents living within 3000 feet and living between 3000 and 5000 feet from a mushroom composting facility and to a control group. Local physicians were interviewed and some air and water testing were performed. No statistically significant impact on health was found

- Heida, H., F. Bartman, and S. C. van der Zee. 1995. Occupational Exposure and Indoor Air Quality Monitoring in a Composting Facility. American Industrial Hygiene Association. 56(1):39-43.

Indoor air quality in enclosed organic waste (food, garden) composting facility showed low VOCs except for limonene (max 140,000microg/m^3). Hydrogen sulfide max =0.5 ppm. Total and gram-negative bacteria and fungi were high.

- Eitzer, B.D., 1995. Emissions of Volatile Organic Chemicals from Municipal Solid Waste Composting Facilites. Environmental Science and Technology. 29:896-902.

Volatile organic chemicals (VOCs) were identified and approximate concentrations measured at various locations on a single day in 8 municipal solid waste composting facilities across the U.S. The facilities used different methods of composting and managed different portions of the municipal solid waste stream. The analysis targeted 67 VOCs plus terpenes, but did not include a number of other VOCs (such as aldehydes, organic acids, organic sulfur compounds and others). The maximum concentrations measured were below workplace exposure limits. Highest emissions were in the early stages of the processes and in the incoming materials as they were shredded except for a group of ketones that were elevated in samples taken later in the processes and that may be produced as part of the composting process.

- Kim, J. Y., J. K. Park, B. Emmons, and D. E. Armstrong. 1995. Survey of Volatile Organic Compounds at a Municipal Solid Waste Cocomposting Facility. Water Environment Research. 67(7):1044-1051.

The concentrations of 9 volatile organic compounds (VOCs) were measured in various parts of a municipal waste composting enclosed facility. Volatilization was the primary mechanism of VOC removal from the wastes for chloroform (74%) and methylene chloride (96%).

- Millner, P. 1995. Bioaerosols and Composting. BioCycle. 1:48-54.

This paper is a summary of the workshop the results of which are presented in more detail in the 1994 article in Compost Science and Utilization summarized below.

- Millner, P. D., S. A. Olenchock, E. Epstein, R. Rylander, J. Haines, J. Walker, B. L. Ooi, E. Horne, and M. Maritato. 1994. Bioaerosols Associated with Composting Facilities. Compost Science and Utilization. 2(4):6-57.

This paper is a review based on a workshop.

Conclusion “Composting facilities do not pose any unique endangerment to the health and welfare of the general public” is based primarily on “the fact that workers were regarded as the most exposed part of the community and where worker health was studied.., no significant adverse health impacts were found. .. [and] in most cases the measured concentrations of the targeted aerobic bacteria, thermophilic (heat loving) fungi, and AF bioaerosols in the residential zones around composting facilities showed that the airborne concentrations of bioaerosols were not significantly different from background.”

There are few data on bioaerosol concentrations, particularly for yard waste composting sites. Some of the non-yard waste studies have down-wind monitoring far away (like half mile and 1 mile). Slightly elevated levels of *Aspergillus fumigatus* at nearest monitoring station (500 feet) downwind of compost pad (WSSC Site 2, Clayton Environmental Consultants, Ltd., 1983) were detected in one study.

Current data are not sufficient to resolve questions regarding the potential health impacts of siting a large yard waste composting facility in relatively close proximity to neighbors.

Recommendations to minimize impacts:

- Design

    - Material handling processes downwind or maximum distance from receptors
    - Forest buffer
- Siting
    - Consider meterorologic and topographic features
    - Proximity can be mitigated with enclosure, good management practices, increased mechanization
- Operation/Mgmt
    - Minimize handling and time it when
        - potential for off-site movement is minimal
        - receptor population is least
    - Minimize disturbance of dusty areas by vehicles
    - Add moisture to minimize dust

- Epstein, E. 1993. Neighborhood and Worker Protection for Composting Facilities: Issues and Actions. Pages 319-338 *in* Science and Engineering of Composting: Design, Environmental, Microbiological and Utilization Aspects. H. A. J. Hoitink and H. M. Keener, eds. Renaissance Publishing, Wooster.

This book chapter reviews the literature.

- Kothary, M. H. and T. Chase. 1984. Levels of *Aspergillus fumigatus* in Air and in Compost at a Sewage Sludge Composting Site. Environmental Pollution Series A. 34:1-14.

Levels of *Aspergillus fumigatus* measured in air downwind of a forced air sludge/woodchip outdoor composting site were highest 1 m downwind (2000-4000 cfu/m^3) and decreased with distance (200-1000 cfu/m^3 50m downwind). Agitation caused increased levels and rainfall decreased them. Levels in residential area 250 m away were 50 and upwind levels were 60. Levels at sites unrelated to the composting site ranged from 0-2. Concentrations did not vary much by season.

- Clark, C. S., R. Rylander, and L. Larsson. 1983. Levels of Gram-Negative Bacteria, *Aspergillus fumigatus*, Dust, and Endotoxin at Compost Plants. Applied and Environmental Microbiology. 45(5):1501-1505.

Bioaerosols were measured at 4 compost plants in Sweden. 3 are sludge (aka biosolids) and solid waste (one outdoor forced air; one bioreactor for 14 d then outdoor; one drum for 2 days then outdoor), fourth is sludge and wood chips (outdoor windrow). Andersen samplers were used to collect samples. *A. fumigatus* was high where waste is processed both in and out doors. About half of the colony forming units are respirable size - higher inside. Dust is generally below 1mg/m^3. Endotoxins ranged from 0.001-0.014 microg/m^3.

- Millner, P. D., D. A. Bassett, and P. B. Marsh. 1980. Dispersal of *Aspergillus fumigatus* from Sewage Sludge Compost Piles Subjected to Mechanical Agitation in Open Air. Applied and Environmental Microbiology. 39(5):1000-1009.

Dispersal of *Aspergillis fumigatus* from pilot-scale field compost piles of sewage sludge was related to pile agitation. Concentrations at 3 and 30 m downwind were not significantly higher than background when compost was not agitated. Application of a model allows concentrations to be predicted.

References Cited Listed Alphabetically

Browne, M. L., C. L. Ju, G. M. Recer, L. R. Kallenbach, J. M. Melius, and E. G. Horn. 2001. A Prospective Study of Health Symptoms and *Aspergillus fumigatus* Spore Counts Near a Grass and Leaf Composting Facility. Compost Science and Utilization. 9(3):241-249.

Buckner, S. C. 2002. Controlling Odors During Grass Composting. Pages 42-47 *in* BioCycle. Vol. 43.

Bunger, J., M. Antlauf-Lammers, T. Schulz, G. Westphal, M. Muller, P. Ruhnau, and E. Hallier. 2000. Health Complaints and Immunological Markers of Exposure to Bioaerosols Among Biowaste Collectors and Compost Workers. Occupational and Environmental Medicine. 57:458-464.

Bunger, J., B. Schappler-Scheele, R. Hilgers, and E. Hallier. 2006. A 5-Year Follow-Up Study on Respiratory Disorders and Lung Function in Workers Exposed to Organic Dust from Composting Plants. International Archives of Occupational and Environmental Health. http://www.springerlink.com/content/82u23r2371414873/fulltext.pdf.

Clark, C. S., R. Rylander, and L. Larsson. 1983. Levels of Gram-Negative Bacteria, *Aspergillus fumigatus*, Dust, and Endotoxin at Compost Plants. Applied and Environmental Microbiology. 45(5):1501-1505.

Cobb, N., P. s. Sullivan, and R. A. Etzel. 1995. Pilot Study of Health Complaints Associated with Commercial Processing of Mushroom Compost in Southeastern Pennsylvania. Journal of Agromedicine. 22(2):13-25.

Curtis, L., M. Ross, V. Persky, R. Wadden, V. Ramakrishnan, and D. Hryhorczuk. 1999. Characterization of Bioaerosol Emissions from a Suburban Yard Waste Composting Facility. Pages 254-257 *in* Bioaerosols, Fungi and Mycotoxins: Health Effects, Assessment, Prevention and Control. E. Johanning, ed, Sarasota Springs, NY.

Danneberg, G., E. Grüneklee, M. Seitz, J. Hartung, and A. J. Driesel. 1997. Microbial and Endotoxin Immissions in the Neighborhood of a Composting Plant. *in* Waste Collection and Recycling - Bioaerosol Exposure and Health Problems. Annals of Agricultural and Environmental Medicine, Denmark.

Department for Environmental Food and Rural Affairs. 2004. Review of the Environmental and Health Effects of Waste Management. Online. Available: http://www.defra.gov.uk/ENVIRONMENT/waste/research/health/index.htm.

Douwes, J., P. Thorne, N. Pearce, and D. Heederik. 2003. Bioaerosol Health Effects and Exposure Assessment: Progress and Prospects. Annals of Occupational Hygiene. 47(3):187-200.

Douwes, J., I. Wouters, H. Dubbeld, L. v. Zwieten, P. Steerenberg, G. Doekes, and D. Heederik. 2000. Upper Airway Inflammation Assessed by Nasal Lavage in Compost Workers: A Relation With Bio-Aerosol Exposure. American Journal of Industrial Medicine. 37(5):459-468.

Eduard, W. and D. Heederik. 1998. Methods for quantitative assessment of airborne levels of noninfectious microorganisms in highly contaminated work environments. American Industrial Hygiene Association Journal. 59(2):113-127. Online. Available: http://proquest.umi.com/pqdweb?did=26593971&sid=3&Fmt=2&clientId=8424&RQT=309&VName=PQD.

Eitzer, B.D., 1995. Emissions of Volatile Organic Chemicals from Municipal Solid Waste Composting Facilites. Environmental Science and Technology. 29:896-902.

Epstein, E. 1993. Neighborhood and Worker Protection for Composting Facilities: Issues and Actions. Pages 319-338 *in* Science and Engineering of Composting: Design, Environmental, Microbiological and Utilization Aspects. H. A. J. Hoitink and H. M. Keener, eds. Renaissance Publishing, Wooster.

Epstein, E. 1997. Bioaerosols. Pages 247-299 *in* The Science of Composting. Technomic Publishing, Lancaster, PA.

Fischer, G., T. Muller, R. Ostrowski, and W. Dott. 1999. Mycotoxins of *Aspergilius fumigatus* in Pure Culture and in Native Bioaerosols from Compost Facilities. Chemosphere. 38(8):1745-1755.

Fischer, G., R. Schwalbe, R. Ostrowski, and W. Dott. 1998. Airborne Fungi and their Secondary Metabolites in Working Places in a Compost Facility. Mycoses. 41:383-388.

Fischer, J. L., T. Beffa, P.-F. Lyon, and M. Aragno. 1998. *Aspergillus fumigatus* in Windrow Composting: Effect of Turning Frequency. Waste Management and Research. 16(4):320-329.

Folmsbee, M. and K. A. Strevett. 1999. Bioaerosol Concentration at an Outdoor Composting Center. Journal of Air and Waste Management Association. 49:554-561.

Gage, J. 2003. Checklist for Odor Management at Compost Facilities. Pages 42-47 *in* BioCycle. Vol. 44.

Gilbert, E. J., A. Kelsey, J. D. Karnon, J. R. M. Swan, and B. Crook. 2002. Preliminary Results of Monitoring the Release of Bioaerosols from Composting Facilities in the UK: Interpretation, Modelling and Appraisal of Mitigation Measures. 2002 International Symposium Composting and Compost Utilization, Columbus, Ohio.

Goldstein, J. and N. Goldstein. 2005. Controlling Odors at Composting Facilities. Pages 22 *in* BioCycle. Vol. 46.

Heida, H., F. Bartman, and S. C. van der Zee. 1995. Occupational Exposure and Indoor Air Quality Monitoring in a Composting Facility. American Industrial Hygiene Association. 56(1):39-43.

Hentz Jr, L. H., W. E. Toffey, and C. E. Schmidt. 1996. Understanding the Synergy Between Composting and Air Emissions. Pages 67-75 *in* BioCycle. Vol. 37.

Heroux, M., T. Page, C. Gelinas, and C. Guy. 2004. Evaluating Odour Impacts From a Landfilling and Composting Site: Involving Citizens in the Monitoring. Water Science and Technology. 50(4):131-137.

Herr, C. E. W., A. zur Nieden, R. H. Bodeker, U. Gieler, and T. F. Eikmann. 2003. Ranking and Frequency of Somatic Symptoms in Residents Near Composting Sites With odor Annoyance. International Journal of Hygiene and Environmental Health. 206:61-64.

Herr, C. E. W., A. zur Nieden, H. Seitz, S. Harpel, D. Stinner, N. I. Stilianakis, and T. F. Eikmann. 2004. Bioaerosols in Outdoor Air - Statement of Environmental Medical Assessment Criteria on the Basis of an Epidemiological Cross Sectional Study. Gefahrstoffe Reinhaltung Der Luft. 64(4):143-152.

Herr, C. E. W., A. zur Nieden, N. I. Stilianakis, and T. F. Eikmann. 2004. Health Effects Associated With Exposure to Residential Organic Dust. American Journal of Industrial Medicine. 46:381-385.

Hryhorczuk, D., L. Curtis, P. Scheff, J. Chung, M. Rizzo, C. Lewis, N. Keys, and M. Moomey. 2001. Bioaerosol Emissions from a Suburban Yard Waste Composting Facility. Annals of Agricultural and Environmental Medicine. 8:177-185.

Ivens, U. I., J. Hansen, N. O. Breum, N. Ebbehoj, M. Nielsen, O. M. Poulsen, H. Wurtz, and T. Skov. 1997. Diarrhoea Among Waste Collectors Associated With Bioaerosol Exposure. Annals of Agricultural and Environmental Medicine. 4:63-68.

Kim, J. Y., J. K. Park, B. Emmons, and D. E. Armstrong. 1995. Survey of Volatile Organic Compounds at a Municipal Solid Waste Cocomposting Facility. Water Environment Research. 67(7):1044-1051.

Kothary, M. H. and T. Chase. 1984. Levels of *Aspergillus fumigatus* in Air and in Compost at a Sewage Sludge Composting Site. Environmental Pollution Series A. 34:1-14.

Lacey, J., P. A. M. Williamson, and B. Crook, eds. 1996. Microbial Emmissions From Composts and Associated Risks - Trials and Tribulations of an Occupational Aerobiologist. CRC Press, Boca Raton, FL.

Marth, E., F. F. Reinthaler, K. Schaffler, S. Jelovcan, S. Haselbacher, U. Eibel, and B. Kleinhappl. 1997. Occupational Health Risks to Employees of Waste Treatment Facililties. Annals of Agricultural and Environmental Medicine. 4:143-147.

Michel Jr, F. C. 2002. Effects of Turning and Feedstocks on Yard Trimmings Composting. Pages 46 *in* BioCycle. Vol. 43.

Millner, P. 1995. Bioaerosols and Composting. Pages 48-54 *in* BioCycle. Vol. 1.

Millner, P. D., D. A. Bassett, and P. B. Marsh. 1980. Dispersal of *Aspergillus fumigatus* from Sewage Sludge Compost Piles Subjected to Mechanical Agitation in Open Air. Applied and Environmental Microbiology. 39(5):1000-1009.

Millner, P. D., S. A. Olenchock, E. Epstein, R. Rylander, J. Haines, J. Walker, B. L. Ooi, E. Horne, and M. Maritato. 1994. Bioaerosols Associated with Composting Facilities. Compost Science and Utilization. 2(4):6-57.

Muller, T., R. A. Jorres, E. M. Scharrer, H. Hessel, D. Nowak, and K. Radon. 2006. Acute Blood Neutrophilia Induced by Short-Term Compost Dust Exposure in Previously Unexposed Healthy Individuals. International Archives of Occupational and Environmental Health. 79:477-482.

Muller, T., R. Thissen, S. Braun, W. Dott, and G. Fischer. 2004. (M)VOC and Composting Facilities. Part 2: (M)VOC Dispersal in the Environment. Environmental Science and Pollution Research - International. 11(3):152-157.

Neef, A., A. Albrecht, F. Tilkes, S. Harpel, C. Herr, K. Liebl, T. Eikmann, and P. Kampfer. 1999. Measuring the Spread of Airborne Microorganisms in the Area of Composting. Schriftenr Ver Wasser Boden Lufthyg. 104:655-664.

Pagans, E., X. Font, and A. Sanchez. 2006. Emission of Volatile Organic Compounds From Composting of Different Solid Wastes: Abatement by Biofiltration. Journal of Hazardous Materials. B131:179-186.

Peterson, M. K., D. L. Johnson, and R. C. Pleus. 2000. Characterization of Emissions From Two Yard-Waste Composting Facilities. Intertox, Inc, Seattle, WA.

Prasad, M., P. van der Werf, and A. Brinkmann. 2004. Bioaerosols and Composting - A Literature Evaluation. Composting Association of Ireland TEO.

Recer, G. M., M. L. Browne, E. G. Horn, K. M. Hill, and W. F. Boehler. 2001. Ambient Air Levels of *Aspergillus fumigatus* and Thermophilic Actinomycetes in a Residential Neighborhood Near a Yard-Waste Composting Facility. Aerobiologia. 17(2):99-108.

Reinthaler, F. F., E. Marth, U. Eibel, U. Enayat, O. Feenstra, H. Friedl, M. Kock, F. P. Pichler-Semmelrock, G. Pridnig, and R. Schlacher. 1997. The Assessment of Airborne Microorganisms in Large-Scale Composting Facilities and their Immediate Surroundings. Aerobiologia. 13:167-175.

Rosenfeld, P., M. Grey, and P. Sellew. 2004. Measurement of Biosolids Compost Odor Emissions From a Windrow, Static Pile, and Biofilter. Water Environment Research. 76(4):310-315.

Rosenfeld, P. E., M. A. Grey, and I. H. Suffet. 2004. Compost Odor Control Using High Carbon Wood Ash. Water Science and Technology. 49(9):171-178.

Rosenfeld, P. E. and I. H. Suffet. 2004. Understanding Odorants Associated With Compost, Biomass Facilities, and the Land Application of Biosolids. Water Science and Technology. 49(9):193-199.

Sanchez-Monedero, M. A., E. I. Stentiford, and C. Mondini. 2003. Biofiltration at Composting Facilities: Effectiveness for Bioaerosol Control. Environmental Science and Technology. 37:4299-4303.

Schlegelmilch, M., J. Streese, W. Biedermann, T. Herold, and R. Stegmann. 2005. Odour Control at Biowaste Composting Facilities. Waste Management. 25:917-927.

Smyth, B. and R. Rynk. 2004. Can Composting BMPs Reduce Air Emissions? Pages 46-50 *in* BioCycle. Vol. 45.

Spencer, R. and C. M. Alix. 2006. Dust Management, Mitigation at Composting Facilities. Pages 55 *in* BioCycle. Vol. 47.

Swan, J. R. M., B. Crook, and E. J. Gilbert. 2002. Microbial Emissions from Composting Sites. Pages 73-101 *in* Issues in Environmental Science and Technology. Vol. 18. R. E. Hester and R. M. Harrison, eds. Royal Society of Chemistry.

Tolvanen, O. K., K. I. Hanninen, A. Veijanen, and K. Villberg. 1998. Occupational Hygiene in Biowaste Composting. Waste Management. 16(6):525-540.

UK Environment Agency. 2001. Agency Position on Composting and Health Effects (Bristol). Pages 6.

van Tongeren, M., L. van Amelsvoort, and D. Heederik. 1997. Exposure to Organic Dusts, Endotoxins, and Microorganisms in the Municipal Waste Industry. International Journal of Occupational and Environmental Health. 3:30-36.

Wheeler, P. A., I. Stewart, P. Dumitrean, and B. Donavan. 2001. Health Effects of Composting - A Study of Three Compost Sites and Review of Past Data, Technical Report P1-315/TR. Pages 111. UK Environment Agency.

Wouters, I. M., S. Spaan, J. Douwes, G. Doekes, and D. Heederik. 2006. Overview of Personal Occupational Exposure Levels to Inhalable Dust, Endotoxin, β(1–3)-Glucan and Fungal Extracellular Polysaccharides in the Waste Management Chain. Annuals of Occupational Hygiene. 50(1):39-53.