

LITERATURE REVIEW

HEALTH IMPACTS OF COMPOSTING AIR EMISSIONS

OVER THE years, there have been concerns related to worker and neighbor health due to airborne particles emitted from composting operations. As a result, there has been a steady stream of studies to evaluate these impacts. This report summarizes a comprehensive review of the literature, providing citations to relevant journal articles and published governmental reports. It has been compiled to help address questions regarding the potential of air emissions from large-scale composting facilities to impact the health of neighbors.

There has been a significant contribution to the literature in the past decade, in part due to studies supported by the European Commission. Much of the available literature addresses on-site investigations relevant to worker health. Some of the literature on worker health is summarized 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. In addition, this summary does not include a comprehensive review of odor or volatile organic compound studies.

This article is an abridged version of a literature summary that includes papers that address air emissions and monitoring of bioaerosols as well as health. The unabridged report can be found at <http://cwmi.css.cornell.edu/compostairemissions.pdf>.

GENERAL OBSERVATIONS FROM THE LITERATURE

Bioaerosols: Airborne particles of concern related to composting fall into the general category of bioaerosols. Bioaerosols are particles of microbial, plant or animal origin and may be called organic dust. They 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. Many bioaerosols are released or produced by the composting process. Microorganisms are frequently absorbed onto dust particles and will be transported along with the dust. Available data are not sufficient to determine whether there is a relationship between different compost feedstocks and the type and concentration of bioaerosols emitted.

Many bioaerosols are known to cause symptoms and/or illness, including a wide range of adverse health effects and infection. Individuals may become increasingly sensitized to some bioaerosols through repeated exposure. There are no ambient or occupational exposure limits for bioaerosols in the U.S.

Variation in exposure to bioaerosols from composting facilities is high even over short time periods. Intermittent releases

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and changes in wind complicate air monitoring since sampling other than for short time intervals can be difficult. A number of studies show that concentrations of bioaerosols downwind of outdoor composting facilities are elevated above background at times to distances on the order of 200 to 500 meters (650 to 1640 feet). Concentrations of bioaerosols in enclosed composting facilities are significantly elevated.

Monitoring Methods: Monitoring bioaerosols is a challenge. Monitoring involves collecting air samples using one or more types of collection devices and then analyzing samples for selected microorganisms and nonliving bioaerosols. All monitoring methods underestimate bioaerosol concentrations due to the spatial and temporal variability of airborne concentrations, the difficulty of keeping the microorganisms alive through the collection process and the limitations of the detection and enumeration processes. Validated standard methods are not yet available for measuring the various bioaerosols. Use of culture techniques in which samples are treated to grow selected organisms will underestimate potential health risks since viable, nonculturable microorganisms — as well as nonliving 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. This method still underestimates exposure to particulates and pieces of bacteria (endotoxin), spores and fungal hyphae, which also can produce irritation, allergy and toxic reactions. Direct spore counts cannot distinguish between some species (such as *penicillium* and *aspergillus*), making exposure indeterminate. DNA analysis methods using PCR technology are being developed for more and more species, but are still limited in what types of organisms can be identified.

Aspergillus fumigatus is ubiquitous in both outdoor and indoor (particularly where there are pets) air. It is a bioaerosol that is often measured because it is known to be emitted during composting. However, measuring *A. fumigatus* is not a good indicator for other bioaerosols since the relative abundance of *A. fumigatus* compared to other microbes varies seasonally in air emissions from composting facilities.

Health Effects: Health effects that have been noted include respiratory symptoms, mucosal membrane irritation, skin diseases and markers showing immune system response. 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. For numerous reasons, workers tend to be healthier than the population in general and particularly the part of the population at relatively high risk. A sample drawn only from workers has a selection bias since obviously some of the most sensitive populations (children, the elderly, people with illnesses) are not included and additionally, workers that experience adverse health effects which they find intolerable will seek employment elsewhere, leaving the "survivors" or "hardy" workers.

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 that were not compost workers. Occupational exposure to bioaerosols may be reduced through a combination of engineering controls, work practices (and other administrative controls), and personal protective equipment.

Compost Process Management: Agitation of the compost (such as turning and screening) produces emissions. Minimizing agitation, application of water to minimize dust, and monitoring wind to avoid agitation when winds are likely to blow towards neighbors can help minimize impacts.

Good management of composting can help minimize odor impacts, however, odors are generated even at well-managed compost facilities. Odors are caused by chemical emissions and are not bioaerosols (this article does not provide a review of the odor literature). 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.

LITERATURE SUMMARIES

In this article, as well as the unabridged report, the summaries are arranged in chronologic order of publication date, starting with the most recent. 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.

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, and 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 at a composting facility for two hours doing moderate exercise. Changes in white blood cell counts, an increase in neutrophils and decrease in eosinophils were measured.



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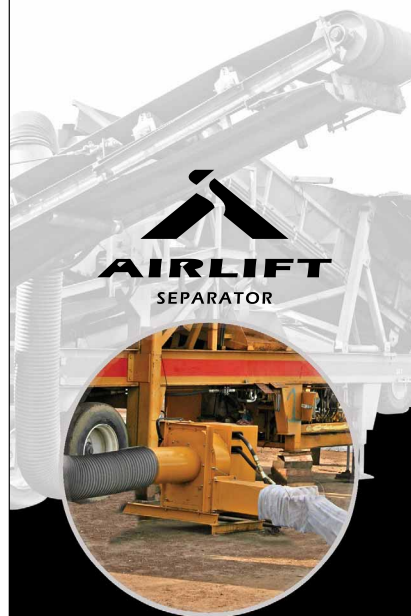
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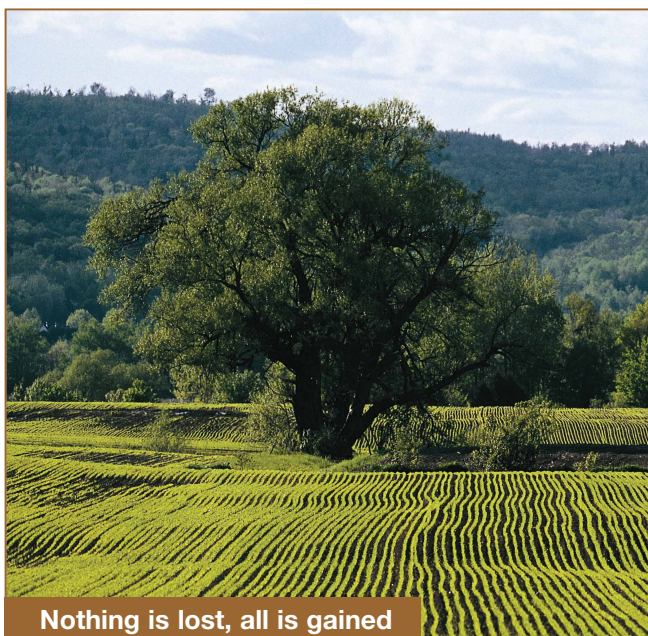
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Wouters, I. M., S. Spaan, J. Douwes, G. Doekes, and D. Heederik. 2006. Overview of Personal Occupational Exposure Levels to Inhalable Dust, Endotoxin, $\beta(1\rightarrow3)$ -Glucan and Fungal Extracellular Polysaccharides in the Waste Management Chain.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

Conclusion: Worker "exposure variability is large, with greater within-worker than between-worker variance. Occupational exposure limits for organic dust and endotoxins are frequently exceeded, suggesting workers are at risk of developing adverse health effects." Worker exposure was monitored in one indoor facility composting household waste, as well as a second study that involved 13 facilities (3 residential organic wastes — indoors; 6 green waste — outdoors; 4 mixed residential organic wastes and green waste — indoors). Endotoxin and dust levels at residential organic waste and mixed composting facilities were higher than at green waste sites; endotoxins at such facilities often exceed Dutch occupational standards. Highest exposure occurs where waste is disturbed. Within-worker variation in exposure, associated with different tasks and locations, was generally higher than between-workers. Variation in bioaerosol composition of dust was high. Caution is required in comparing different studies due to method differences.

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.

Conclusion: 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. Total bioaerosols (total bacteria, molds and thermophilic actinomycetes) were found at $>10^5$ CFU/m³ in outdoor air in the vicinity of an outdoor composting facility, dropping to background concentrations within 550 m. 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.

Conclusion: An association was demonstrated between residential bioaerosol pollution and irritative airway complaints as well as excessive fatigue and shivering (symptoms that are reported at workplaces handling such materials). Significantly higher than background concentrations of thermophilic actinomycetes, total bacteria and molds were measured in air downwind within 200 m from an outdoor composting site (type of feedstock not specified), dropping to near background within 300 m. The highest levels measured within 200 m of the site ($>10^5$ CFU/m³) are similar to occupational composting exposures. A physician-administered survey found airway symptoms; no odor annoyance was observed in residents in highest exposure (150-200 m downwind) vs. further away (400-500 m). Residents reporting odors did not "overreport" health disturbances, indicating that odors did not bias reports of illness.

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.

Conclusion: Risk assessment for bioaerosols is "seriously hampered by the lack of valid quantitative exposure assessment methods." This is a review article. Culture methods for measurement of bioaerosols is more qualitative than quantitative. It has poor reproducibility, does not measure some organisms and does not measure nonliving constituents. Nonculture methods rely on mi-

RECOMMENDATIONS TO MINIMIZE POTENTIAL HEALTH IMPACTS

WHEN evaluating steps that minimize potential health impacts from a composting facility, the most important is to consider appropriate management practices and facility design that suit the site and the materials. For example, compost facilities at sites in close proximity to people may need to be enclosed in order to control air emissions. The possibility of reducing potential health impacts by following good practices is recognized (Millner, et al., 1994).

Recommendations to minimize impacts include:

Siting

- Consider how meteorological and topographic features affect air flow
- Establish buffers between receptors and the composting facility

Design

- Site material handling processes

downwind or maximum distance from receptors

- Enclose facilities to reduce off-site exposures if needed
- Install pad type suited to the operation
- Minimize ponding through site grading and design

Operation/Management

- Maintain good air flow through the compost
- Minimize handling
- Turn compost based on temperatures, not a schedule
- Restrict material movement to times when the potential for off-site movement is minimal (low wind) and receptor population is least (time of day, avoid weekends and holidays)
- Minimize disturbance of dusty areas by equipment
- Minimize dust by adding moisture to materials when moving them and to traffic areas, and watering dry materials and dusty areas

croscopes or flow cytometry to identify and count. "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."

In general, exposure to bioaerosols can be associated with a wide range of adverse health effects (including contagious diseases, acute toxic effects, allergies and cancer as well as possibly preterm births or late abortions and dermatitis). Workers in the 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.

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.

Conclusion: 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. This brief paper reports results of an epidemiologic study of people living in the vicinity of three composting plants.

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.

Conclusion: Participant diaries showed no correlation between symptoms and A. fumigatus concentrations. Aspergillus fumigatus spore concentrations are higher in vicinity of a 40-acre yard waste composting site than background. The study used self-reporting through diaries to record symptoms, 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. No other bioaerosols were measured.

Wheeler, P. A., I. Stewart, P. Dumitrean, and B. Donovan. 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.

Conclusion: "Composting activities do emit bioaerosols at levels which can pose a hazard to susceptible members of the public." This is a literature review and report on monitoring of emissions from three composting plants (two green waste turned windrow facilities and one mixed waste in-vessel facility). A buffer zone of 250 m around composting sites is suggested. Concentrations for total bacteria of 1000 CFU/m³, 1000 CFU/m³ for total fungi, 300 CFU/m³ for gram-negative bacteria and 250 µg/m³ for inhalable dust are suggested as conservative (low) protective values. These concentrations are generally exceeded at composting sites (10⁵-10⁶ CFU/m³ of bacteria and gram negative bacteria and 10³-10⁴ CFU/m³ 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 onsite fell within the range of 10³-10⁷ fungi and bacteria during compost agitation. 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.

Bunger, J., M. Antlauf-Lammers, T. Schulz, G. Westphal, M. Muller, P. Ruh-

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nau, 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.

Conclusion: 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 antibody 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.

Conclusion: "Compost workers are at risk of developing acute and possibly chronic inflammatory responses in the upper airways..." Workers in a 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. Bioaerosols were lower after process improvements, however nasal and respiratory symptoms were unchanged. 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.

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

Conclusion: Elevated IgE (a trace serum protein [antibody] associated with allergic reactions) was detected in compost workers, however no statistically significant increase in allergic diseases was found. Several measures of allergy, inflammation and lung function were measured in 117 workers at two composting and three waste sorting facilities and compared with a control group. Eye and mucous membrane irritation, coughing and decreased lung function were measured.

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*. 2(2):13-25.

Conclusion: No significant health hazard associated with the mushroom compost site could be demonstrated. In response to residents' complaints, a symptom questionnaire was administered to 100 residents living within 3,000 feet (inner zone) and living between 3,000 and 5,000 feet (outer zone) from a mushroom composting facility, and to two control groups. Local physicians were interviewed and some air and water testing were performed. Inner zone residents reported more symptoms than those in the outer zone, but not more than one of the control groups. No statistically significant impact on health was found.

Millner, P. D., S. A. Olenchok, 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.

Conclusion: "Composting facilities do not pose any unique endangerment to the health and welfare of the general public." This paper is a review based on a workshop. It provides a review of the literature that was available in the early 1990s. The conclusion 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 *Aspergillus fumigatus* bioaerosols in the residential zones around composting facilities showed that the airborne concentrations of bioaerosols were not significantly different from background."

There were few available data on bioaerosol concentrations, particularly for yard waste composting sites. Some of the non-yard waste studies had downwind monitoring far away (i.e. 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 (as of early 1990s) were found to be insufficient to resolve questions regarding the potential health impacts of siting a large yard waste composting facility in relatively close proximity to neighbors.

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