



Enclosure of Composting Operations to Minimize Bioaerosol Emissions into Ambient Air

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Abstract

A microbial evaluation was performed at a composting facility where all mechanical agitation of composting materials was performed in an enclosed, negatively pressurized structure in which air is filtered before being discharged into the atmosphere. The objective of this evaluation was to determine if bioaerosol emissions from the composting processes were effectively contained within the enclosed facility. *Aspergillus fumigatus* was the dominant fungus in settled dust and compost in the facility. The Gram-negative bacteria concentration in compost exceeded 10^{11} cfu/g. Air sampling in and around the composting facility was performed by spore trap for molds and by polycarbonate filter cassettes for endotoxins. The highest concentrations of airborne spores (by spore traps) and endotoxin within the facility were about 10^5 spores/m³ and 10^2 endotoxin units/m³. By contrast, much lower concentrations of fungal spores (range from about 40 to 800 spores/m³) and endotoxins (< 1.0 endotoxin units/m³) were found in ambient air both upwind and downwind of the facility. *Penicillium* and *Aspergillus* spores were present in only about 20% of both upwind and downwind ambient air samples. The results indicated that composting within the enclosed facility does not add to the bioaerosol burden in nearby ambient air.

Author's Note

Key words: *Aspergillus*; biosolids, composting, endotoxin, engineering controls

Introduction

Emission of malodors and microbial particulate, especially *Aspergillus fumigatus*, into ambient air has been a concern for new composting operations. When compost in open piles is mechanically agitated, for example by a windrow machine, fungal spores are transported for various distances downwind from the operation. Millner et al. (1980) showed that when open piles of sewage sludge compost are subject to mechanical agitation, the average *A. fumigatus* concentration 50 m downwind of the pile was 50 colony forming units (cfu)/m³ compared to 2 cfu/m³ at upwind locations. Kothary et al. (1984) detected slightly increased concentrations of *A. fumigatus* in a residential area 250 m downwind of an open facility actively composting sewage sludge. In a study in Islip, New York (State of New York, 1994), involving the collection of airborne fungi by spore trap, elevated concentrations of *Aspergillus* sp. were detected in a residential neighborhood about 500 m from an open composting operation when prevailing winds were blowing from the facility toward the neighborhood.

We had the opportunity to perform a microbial evaluation at a new composting facility in Rochester, New Hampshire, where all mechanical agitation of compost was performed in an enclosed structure. In addition, this evaluation was performed at a time when the ground around the facility was snow- and ice-covered so as to minimize the confounding effect of bioaerosol emissions of fungi from natural out-

door soil and botanical sources. The primary objective of this evaluation was to determine if bioaerosol emissions from the composting processes in Rochester were effectively contained within the enclosed facility.

Facility Description

Composting is conducted entirely within a building where biosolids from primary and secondary wastewater treatment residuals are mixed on a 1.5:1 wet weight basis with botanical materials such as leaves, brush, saw dust, and yard wastes. Biosolids and botanical materials are trucked into the facility's mixing area through doors that remain open only for short periods of time each day. Biosolids and botanical materials are mixed and then loaded into the front end of composting vessels or bays which are approximately 76 m long, 2 m wide, and 1.8 m deep. The materials in the composting vessels are stirred by a mechanical agitator and batch transported down the vessel by the agitator at a rate of approximately 3.6 m/day.

Air is periodically forced upward through the mixture by a forced aeration system in the floor of the vessel. The rate of aeration during the composting process is controlled to maintain a temperature of 55°C to 65°C during the first week and thereafter at a temperature of 40°C to 50°C. The space about the vessels is warm and misty because a considerable amount of heat and water vapor is given off during the aeration of compost.

To maintain the composting process areas at a slight negative pressure relative to ambient air, air from the space above the composting vessels is continuously exhausted. The exhaust air stream leaving the building passes through a "biofilter" that is approximately 1 m thick. This biofilter consists of a compacted mixture of wood chips, bark mulch, and leaf compost. The primary purpose of filtration of the exhaust air stream is to remove odorous air contaminants (Kuter et al., 1993). The biofilter is also thought to be effective in removing particulate from the exhaust air stream although it is not specifically designed to do so.

At the output end of each vessel, finished compost is discharged into a pile that is located within the facility enclosure. Doors at the discharge end of the facility are periodically opened so that front-end

loading vehicles can remove compost for transport to the end user.

Materials and Methods

Approximately 100 g of material was removed separately from the surface and also at a depth of at least 15 cm from each pile of finished compost that had been discharged from the output end of the vessels. The surface compost samples were combined and then sieved on a screen with mesh openings of approximately 1 mm. Subsurface compost samples were combined and processed in a similar manner. Using disinfected knives and spatulas, an additional sample of settled dust was collected from the surfaces of a metal catwalk located approximately 3 m above the output end of the composting vessels.

Surface and subsurface compost that passed through the openings of the screen as well as settled dust from the catwalk were analyzed by serial dilution for culturable 23°C to 28°C (mesophilic), 40°C to 42°C (thermotolerant), and 50°C to 60°C (thermophilic) microorganisms. Fungi were enumerated and identified by culture on a combination of yeast malt extract agar, inhibitory mold agar with gentamicin and chloramphenicol, and yeast malt extract with gentamicin and chloramphenicol. Bacteria were enumerated on culture media including buffered charcoal yeast extract agar, blood (5% sheep blood) agar, and MacConkey agar.

The endotoxin content in the sieved compost materials was determined by the *in vitro* assay based on the reaction of *Limulus* ameobocyte lysate with lipopolysaccharide after the method of Reynolds and Milton (1993). The concentration of endotoxin is expressed as endotoxin units (EU) of U.S. Reference Standard endotoxin EC-5 per mg of material. One EU equals 0.1 ng of endotoxin.

Airborne fungal spores were collected with a personal Burkard spore trap operating at a flow rate of 0.01 m³/minute. Sampling times varied from 2 seconds in the dustiest locations in the composting facility to a maximum of 14 minutes in the outdoor air. Fungal spores were identified according to morphological taxa by direct microscope observation using an oil immersion 100x objective.

Airborne endotoxin was collected on polycarbonate filters (pore size 0.4 µm) in 37 mm diameter cassettes. The air flow rate through the cassette was

0.0105 m³/minute and the total air volume ranged from 0.15 to 2.5 m³. Endotoxin was quantified according to the method of Reynolds and Milton (1993).

Results and Discussion

The microbial composition of finished compost and settled dust from catwalk surfaces above composting vessels is presented in Table 1. *Aspergillus fumigatus* was a dominant isolate in some of these samples, especially at incubation temperatures of 40°C to 42°C (optimal growth for this species occurs at approximately 40°C [Joseph, 1983]). Thus, the settled dust from the surfaces of the catwalk above the composting vessels contained thermotolerant *A. fumigatus* at a concentration exceeding 10⁷ cfu/g. This suggests that *A. fumigatus* is likely to be the dominant mycoflora in air exhausted through the biofilter from the facility.

Total concentrations of Gram-negative bacteria, Gram-positive bacteria, and actinomycetes each exceeded 10¹¹ CFU/g in finished compost and in settled compost dust (Table 1). The endotoxin concentration in finished compost (Table 1) was approximately 900 EU/mg, which is somewhat higher than that reported for house dust (Michel et al., 1994), but less than that found in cotton dusts (Fischer, 1982).

Air sampling by spore trap was performed in the office areas of the composting facility on February 23, 1994, and in compost processing areas (ground level between composting vessels and on catwalk above vessels) on March 9, 1994 (Table 2). Air sampling was also performed in the ambient air both upwind and downwind of the facility on February 23, 1994, and on March 7 and 9, 1994, at a time when snow and ice covered the ground around the facility (Table 3).

The average concentration of spores in the two samples from the office area in the facility was 640 spores/m³ (Table 2). *Cladosporium* sp. was the predominant identified spore in both samples.

The average concentration of spores in the 11 samples collected in the processing areas of the composting facility was 4 x 10⁴ spores/m³ (Table 2). The concentration of spores in samples from the processing area varied from below the limit of detection

(about 1,000 spores/m³) to 1.1 x 10⁵ spores/m³. *Penicillium* and *Aspergillus* spores were not detected even though 5 of the 11 samples were collected on the catwalk above the composting vessel output area. This was surprising because *A. fumigatus* was the dominant fungus found in settled dust on catwalk surfaces (Table 1).

Cladosporium sp., hyphal fragments, and unidentified spores (possibly actinomycetes) were found in most air samples collected in the processing areas of the composting facility. Some samples, both at ground level between composting vessels and on the catwalk, contained botanical tissue fragments identifiable by the presence of tracheary elements, fibers, and parenchyma cells.

A total of 13 upwind and 25 downwind ambient air samples at the composting facility were collected on February 23, March 7, and March 9, 1994. While most samples were collected within 500 m of the facility, a few remote upwind samples were obtained at a location 16 km away. It is not uncommon during the late winter in southeastern New Hampshire to have a substantial change in prevailing wind direction over a period of only a few hours. This was anticipated and the sampling strategy included collection of samples both upwind and downwind of the facility at approximately the same time. Sampling locations in Table 3 are presented as either upwind or downwind without regard to the exact physical site because of the changeable direction of the prevailing wind during the 3 days when the evaluation took place.

The concentration of spores in the 13 samples collected at upwind locations varied from 40 to 770 spores/m³ (Table 3). *Penicillium* and *Aspergillus* spores were found in only three of these samples. *Cladosporium* sp. spores and hyphal fragments were found in 12 and 3 samples, respectively. The average spore concentration in remote (480 spores/m³) and nearby (380 spores/m³) upwind locations was similar (Table 3).

The average concentration of spores in 25 downwind samples was 320 spores/m³ (range 40 to 840 spores/m³ [Table 3]). *Penicillium* and *Aspergillus* and *Cladosporium* sp. spores were present in 5 and 8 samples, respectively. Hyphal fragments were found in nearly half of the downwind samples.

Table 1
Microbial Composition of Materials from Compost Facility

Type and Source of Material	Concentration of Microbial Component*
23 °C to 28 °C Microorganisms	
Surface layer of finished compost in discharge area	1 x 10 ⁷ GPB 3.5 x 10 ⁶ GNB 950 <i>Candida</i> sp. 390 <i>Aspergillus fumigatus</i> group
Finished compost 15 cm below surface layer in discharge area	9 x 10 ⁸ GNB 4.3 x 10 ⁸ GPB 5.3 x 10 ⁴ <i>Aspergillus fumigatus</i> group 5.3 x 10 ⁴ <i>Penicillium</i> sp. 5.3 x 10 ⁴ <i>Paecilomyces</i> sp.
Settled dust on catwalk surfaces above output end of composting vessels	3.5 x 10 ⁹ GNP 1 x 10 ⁹ GPB 8 x 10 ⁴ <i>Aspergillus fumigatus</i> group 9 x 10 ⁴ <i>Penicillium</i> sp.
40 °C to 42 °C Microorganisms	
Surface layer at finished compost in discharge area	1.7 x 10 ⁹ <i>Candida</i> sp. 1.2 x 10 ⁹ GPB 5 x 10 ⁸ GNB 1.5 x 10 ⁵ <i>Aspergillus fumigatus</i> group
Finished compost 15 cm below surface layer in discharge area	1.9 x 10 ⁹ GNB 3.7 x 10 ⁸ GPB 5.3 x 10 ⁷ Actinomycetes 5.3 x 10 ⁴ <i>Gilmaniella</i> sp.
Settled dust on catwalk surfaces above output end of composting vessels	8 x 10 ⁸ GNB 1.7 x 10 ⁸ GPB 4 x 10 ⁷ <i>Aspergillus fumigatus</i> group
50 °C to 60 °C Microorganisms	
Surface layer of finished compost in discharge area	4.2 x 10 ¹² GNB 1.7 x 10 ¹² GPB 2.3 x 10 ¹¹ Actinomycetes 390 <i>Gilmaniella</i> sp. 150 <i>Aspergillus fumigatus</i> group
Finished compost 15 cm below surface layer in discharge area	8.2 x 10 ¹¹ GPB 6.9 x 10 ¹¹ Actinomycetes 1.5 x 10 ¹¹ GNB 5.3 x 10 ⁴ <i>Gilmaniella</i> sp.
Settled dust on catwalk surfaces above output end of composting vessels	1.4 x 10 ¹² Actinomycetes 4 x 10 ¹¹ GNB 3.2 x 10 ¹¹ GPB 8 x 10 ⁴ <i>Aspergillus clavatus</i> group
Endotoxin	
Surface layer of finished compost in discharge area	8.4 x 10 ³ EU
Finished compost 15 cm below surface layer in discharge area	9.8 x 10 ³ EU

*Concentration of microorganisms in cfu/g; endotoxin concentration in endotoxin units (EU)/mg.

GPB equals Gram-positive bacteria

GNB equals Gram-negative bacteria

The analytical results in Table 3 show that the range of spore concentrations found at upwind and downwind locations is similar. The percentage of upwind and downwind samples containing *Penicillium* and *Aspergillus* spores is similar. This, together with the similar range of total spore concentrations at upwind and downwind locations, suggests that fungal spore emissions from the composting facility are insufficient to result in a measurable increase in airborne fungi at nearby downwind locations.

Three air samples collected within the composting facility were analyzed for endotoxin (Table 4). Endotoxin concentration in two of the samples (one sample in the catwalk area above the output end of the composting vessels; second sample at ground level between composting vessels) was greater than 100 EU/m³. These levels exceed the endotoxin

concentrations that have been associated with adverse respiratory health effects in other industries (Olenchok, 1994).

Five air samples analyzed for endotoxin were collected outdoors, two at the edge of the biofilter, two at locations 12 m and 50 m downwind from the facility, and one sample 55 m upwind of the facility (Table 4). The concentration of endotoxin in the two sequential samples collected at the edge of the biofilter was 23.5 and 0.14 EU/m³. Other than possible dislodgment and aerosolization of botanical material from the biofilter during sampling, there was no apparent reason for variation in the sampling results.

The endotoxin concentrations in the samples collected 12 m and 50 m downwind from the facility were less than 1.0 EU/m³ (Table 4). The upwind endotoxin concentration was 0.18 EU/m³. Back-

Table 2

Airborne Particulate Collected by Spore Trap Within Composting Facility

Sample Location and Concentration of Spores*	Kinds of Spores and Particulate
Office area; 480 and 800 spores/m ³ (N=2)	<i>Cladosporium</i> and unidentified spores in both samples
Processing area; <LOD* to 1.1 x 10 ⁵ spores/m ³ (N=11; x=4 x 10 ⁴ spores/m ³)	Hyphal fragments in 7 of 11 samples; <i>Cladosporium</i> in 6 of 11 samples; botanical fragments in 5 of 11 samples; unidentified spores in 10 of 11 samples

*Limit of detection (LOD) equals about 1,000 spores/m³ for the processing area; x equals average.

Table 3

Airborne Particulate Collected by Spore Trap in Ambient Air

Sample Location and Concentration of Spores*	Kinds of Spores and Particulate
1 to 16 km upwind; 150 to 770 spores/m ³ (N=5; x=480 spores/m ³)	<i>Cladosporium</i> and unidentified spores in all samples; <i>Penicillium-Aspergillus</i> spores in 2 of 5 samples; hyphal fragments in 2 of 5 samples
2 to 180 m upwind; 40 to 540 spores/m ³ (N=8; x=380 spores/m ³)	Unidentified spores in 6 of 8 samples; <i>Cladosporium</i> in 7 of 8 samples; <i>Penicillium-Aspergillus</i> 1 of 8 samples; hyphal fragments in 1 of 8 samples
3 to 120 m downwind; 40 to 840 spores/m ³ (N=13; x=420 spores/m ³)	Unidentified spores in 10 of 13 samples; <i>Cladosporium</i> in 6 of 13 samples; <i>Penicillium-Aspergillus</i> in 2 of 13 samples; hyphal fragments in 9 of 13 samples;
360 to 540 m downwind; <LOD to 720 spores/m ³ (N=12; x=210 spores/m ³)	Unidentified spores in 10 of 12 samples; <i>Penicillium-Aspergillus</i> in 3 of 12 samples; <i>Cladosporium</i> in 2 of 12 samples; hyphal fragments in 3 of 12 samples

*x equals average; limit of detection (LOD) equals about 40 spores/m³

Table 4
Airborne Endotoxin Within Composting Facility and Outdoors

Sample Location	Endotoxin Concentration (EU/m³)
Processing areas within facility (N=3)	98 (range 16 to 168)
Outdoors at edge of biofilter (N=2)	23.5 in first sample, 0.14 in second sample
Outdoors, 12 m downwind of facility	0.95
Outdoors, 50 m downwind of facility	0.60
Outdoors, 55 m upwind of facility	0.18

ground endotoxin concentrations of approximately 0.1 to 1.0 EU/m³ are considered typical of ambient air (Olenchok, 1994; Milton, 1999). The collective analytical results of sampling conducted in ambient air suggest little or no transmission of Gram-negative bacterial products into nearby ambient air around the composting facility during wintertime operating conditions.

The results indicate that composting within the enclosed facility in Rochester, New Hampshire, contributes little or no fungal spores and endotoxin to the nearby ambient air around the facility. Control of bioaerosol emissions is achieved by negative pressurization of the air above the composting process so that the release of airborne particulate through building openings is minimized. In addition, all air exhausted from the composting facility is passed through a biofilter prior to discharge into the outdoor environment. This kind of enclosed composting operation is environmentally advantageous over open field windrow composting where mechanical agitation almost certainly results in emission of spores and other microbial particulate into nearby downwind locations.

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