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# BIOAEROSOL EMISSIONS FROM A SUBURBAN YARD WASTE COMPOSTING FACILITY

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**Abstract:** The purpose of this study was to assess worker and community exposure to bioaerosols emitted from a suburban yard waste composting facility in northern Illinois, USA. Characterization of on- and off-site viable bioaerosols was undertaken through a total of 288 on- and off-site Andersen samples conducted over 10 sampling days. A total of 46 dust samples and 38 Kramer-Collins spore samples were also collected in this period. Evaluation of the impact of the facility on community bioaerosol concentrations was undertaken by comparing on- and off-site measurements by sampling locations, wind direction, and site activity. On-site concentrations of total spores, *Aspergillus/Penicillium* spores, total bacteria, Gram-positive bacteria, Gram-negative bacteria, actinomycetes, total particulates, endotoxin, and β-1,3 glucans were higher than off-site concentrations. Total fungal spores averaged 13,451 spores/$m^3$ (range 5,223-26,067) on-site and 8,772 spores/$m^3$ (range 243-18,276) off-site. Viable bacterial airborne concentrations (in cfu/$m^3$) averaged 11,879 on-site (range 480-78,880) and 3,204 off-site (range 160-17,600). Mean levels of endotoxins (in ng/$m^3$) were 1.94 on-site (range 0.12-6.06) and 0.14 off-site (range 0.01-0.41). Mean levels of β-1,3 glucans (in ng/$m^3$) were 2.17 on-site (range 0.12-14.45) and 0.24 off-site (range 0.01-0.78). Mean total viable fungi, on the other hand, were higher off-site than on-site (8,651 vs 3,068 cfu/$m^3$). On-site concentrations of total bacteria, Gram-positive bacteria, Gram-negative bacteria, and actinomycetes demonstrated a statistically significant pattern of decreasing concentration with distance from pile and higher downwind vs upwind concentrations. Mean on-site concentrations of viable bacteria, viable fungi, and endotoxins were significantly higher during periods of activity compared to periods of no activity. Off-site concentrations of bacteria were also significantly higher during periods of activity compared to no activity. The highest concentrations of total particulates, endotoxin, and β-1,3-glucans were observed in the personal samplers worn by workers at the facility. One personal sampler measured an Asp f1 exposure of 22.17 ng/$m^3$ during turning activity. Peak exposures to several bioaerosol constituents were sufficiently high to warrant use of respirators by workers during periods of pile activity that lead to dust generation.

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## INTRODUCTION

Composting is a biological treatment process in which organic wastes are transformed into agriculturally useful products such as compost. Many areas of the world are increasingly using community composting facilities due to lack of landfill space and concern over air pollutants produced by landscape waste burning. In Illinois, two laws

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ban landscape waste in landfills and require all counties with a population of over 100,000 to recycle at least 25% of their solid waste.

Several studies have assessed bioaerosol exposures at and around composting facilities. Fischer and colleagues [12-14] sampled airborne fungal propagules and metabolites from an indoor German compost facility in January, April and August. Total number of fungi ranged from $10^6$–$10^7$ cfu/m$^3$ year-round in highly contaminated areas such as the loading area and compost pile hall. High airborne concentrations of viable *Aspergillus*, *Penicillium*, *Paecilomyces* and *Rhizopus* were also collected in addition to measurable levels of the *Aspergillus* mycotoxins tryptoquivaline and trypacidin in the dust. Jager *et al.* [21] measured biaerosol concentrations at two German indoor composting plants during quiet periods and during periods of shredding and mixing compost. Median bacteria concentrations (in cfu/m$^3$) at the two plants ranged from 1,979–3,869 during quiet periods to 21,201–84,806 during shredding periods. Concentrations at an upwind control location ranged from 495–1,312. Median fungal concentrations (in cfu/m$^3$) at the two plants ranged from 106–777 during quiet periods to 5,151–19,064 during shredding periods with an upwind control sample of 141–345.

Investigators analyzed air samples for total spores and viable fungi at four locations on and around the Islip, New York yard waste composting facility [6]. The sampling sites included: onsite, 540 m downwind prevailing winds, 460 m upwind, and a control site 8 km from the facility. Total spore concentrations were similar for all four sites and averaged 7,400 to 13,000 total spores/m$^3$. Airborne *Aspergillus* and thermophilic actinomycetes levels were sigificantly elevated in the 540 m downwind site as compared to other control sites. Average viable *Aspergillus* concentrations were 603 (onsite), 81 (downwind), 20 (upwind), and 46 cfu/m$^3$ (control) [6].

An Oklahoma, USA, study of a yard waste facility reported that mean fungi and bacteria concentrations (in cfu/m$^3$) peaked at 5,059 and 972 respectively 30 m downwind from the site as compared to 1,000 and 450 respectively several km from the site [15]. An Ontario, Canada, study of personal exposures at a leaf and yard waste composting site found total concentrations of viable bacteria and fungi ranged from 700 cfu/m$^3$ among workers shipping fresh compost to 137,700 cfu/m$^3$ among workers curing compost [40]. Airborne endotoxin concentrations ranged from 1.9–47 ng/m$^3$. An Austrian study of a yard and kitchen waste compost site [33] reported median airborne bacterial concentrations were 4,500 cfu/m$^3$ at a site 3 m from the windrows but only 120 to 430 cfu/m$^3$ at five sites 200 to 700 meters from the compost facility. Median total fungal concentrations were 6,500 cfu/m$^3$ 3 m from windrows but only 1,100 to 1,700 cfu/m$^3$ at five sites 200 to 700 m from the compost facility.

Herr *et al.* [20] reported a wide range of bacterial and fungal concentrations at three composting plants in Hesse, Germany - between 5–$10^6$ cfu/m$^3$ bacteria and $10^1$–$10^5$ cfu/m$^3$ fungi. Schappler-Scheele *et al.* [36] reported fungal concentrations from 10,000–1,000,000 cfu/m$^3$ and endotoxin concentrations of 0.02–304 ng/m$^3$ at German compost facilities. Gottlich *et al.* [19] reported fungal concentrations at a composting plant of 5,000–50,000,000 cfu/m$^3$. Sisgaard *et al.* [37] reported mean fungal concentrations at a composting plant of 67,536 cfu/m$^3$. Pfirrman and Bosche [32] reported mean plaque forming viruses concentrations of 0–711 plaques/m$^3$ at a composting facility. Additional studies have examined bioaerosol concentrations at sewage facilities, cut grass, food and wood processing areas and other operations related to composting [7, 11, 23, 28, 29].

A few studies have looked at health effects of composting. Douwes *et al.* [10] found that lung lavage concentrations of inflammation markers (nitric oxide,

**Table 1.** Summary of 144 viable Andersen samples taken on 10 sampling days between 6-09-1995–13-11-1995.

| No. | Location[a] | Number of samples | Fungal samples | | | | | Bacterial samples | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean cfu/m$^3$ | Median cfu/m$^3$ | Range cfu/m$^3$ | SD | Fraction of value 1 m downwind | Mean cfu/m$^3$ | Median cfu/m$^3$ | Range cfu/m$^3$ | SD | Fraction of value 1 m downwind |
| 1 | North | 19 | 6,913 | 4,160 | 80-25,520 | 7,073 | 1.89 | 4,353 | 2,640 | 480-17,600 | 4,336 | 0.23 |
| 2 | South | 18 | 2,088 | 2,400 | 160-3,600 | 1,267 | 0.57 | 2,235 | 1,810 | 160-9,840 | 2,175 | 0.12 |
| 3 | East | 7 | 34,434 | 7,120 | 1,040-94,320 | 39,219 | 9.35 | 2,765 | 1,760 | 1,280-5,600 | 1,759 | 0.14 |
| 3[b] | West | 11 | 5,985 | 2,560 | 720-21,520 | 6,777 | 1.64 | 3,083 | 2,080 | 560-9,120 | 2,687 | 0 16 |
| 4 | 1 meter downwind | 18 | 3,657 | 2,400 | 480-17,680 | 4,077 | 1.00 | 19,044 | 6,840 | 640-78,880 | 24,564 | 1.00 |
| 5 | 10 meter downwind | 18 | 3,098 | 2,360 | 480-13,680 | 3,112 | 0.85 | 9,793 | 4,440 | 480-41,600 | 11,089 | 0.51 |
| 6 | Downwind fenceline | 17 | 17,871 | 5,120 | 960-7,560 | 28.851 | 4.89 | 5,915 | 4,640 | 640-19,120 | 5,094 | 0.31 |
| 7 | 10 meter upwind | 18 | 2,448 | 2,320 | 480-13,800 | 1,402 | 0.67 | 6,800 | 3,880 | 560-26,240 | 7,638 | 0.36 |
| 8 | Upwind | 18 | 8,440 | 4,800 | 80-57,680 | 13,269 | 2.31 | 4,044 | 4,880 | 320-8,400 | 2,427 | 0.21 |

[a]North, South, East and West samples were taken outside of compost facility. 1 meter, 10 meter and fenceline samples were taken on compost facility grounds. [b]Sample 3 was taken at an east site (3) or west site (3b) depending on which sampling location was more downwind relative to the prevailing wind.

**Table 2.** Summary of fungal concentrations and genera composition for the 55 off-site (north, south, east and west sites) and the 54 on-site samples taken 1 and 10 meters (downwind and upwind) from the piles.

| | 55 off-site samples | | | | 54 on-site samples at 1 and 10 meters | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean cfu/m$^3$ | Median cfu/m$^3$ | Range cfu/m$^3$ | Percent of total fungi | Mean cfu/m$^3$ | Median cfu/m$^3$ | Range cfu/m$^3$ | Percent of total fungi |
| Total | 8651 | 3200 | 80-94,320 | 100.0 | 3068 | 2400 | 480-17,680 | 100.0 |
| *Aspergillus* | 5601 | 1525 | 0- 59,727 | 64.7 | 1397 | 739 | 0-13,206 | 45.5 |
| *Penicillium* | 1403 | 505 | 0-14,450 | 16.2 | 647 | 454 | 0-3,920 | 21.1 |
| *Cladosporium* | 350 | 251 | 0-2,706 | 4.0 | 239 | 170 | 0-1,065 | 7.8 |
| *Alternaria* | 327 | 84 | 0-7,715 | 3.8 | 144 | 80 | 0-678 | 4.7 |
| Yeasts | 182 | 0 | 0-3,982 | 2.1 | 142 | 83 | 0-662 | 4.7 |
| *Rhizopus* | 13 | 0 | 0-420 | 0.15 | 173 | 0 | 0-4,724 | 5.6 |
| *Epicoccum* | 124 | 0 | 0-1,654 | 1.4 | 23 | 0 | 0-256 | 0.74 |
| *Mucor* | 48 | 0 | 0-766 | 0.55 | 99 | 0 | 0-691 | 3.2 |
| *Verticillium* | 49 | 0 | 0-498 | 0.56 | 13 | 0 | 0-169 | 0.42 |
| *Fusarium* | 22 | 0 | 0-532 | 0.25 | 6 | 0 | 0-85 | 0.20 |
| *Curvularia* | 36 | 0 | 0-702 | 0.41 | 9 | 0 | 0-169 | 0.29 |

Note: minor genera and unidentified fungi are omitted, hence total of fungi genera listed does not equal total fungi.

myeloperoxidase and interleukin-8) were 1.1–4.8 times higher in compost workers than control workers. These compost workers were involved in large-scale composting of household food and yard waste in an indoor facility and did not wear respiratory protection. The compost workers were exposed to geometric mean endotoxin and β-1,3-glucan airborne concentrations ranging from 29 EU/m$^3$ to 527 EU/m$^3$ endotoxin and 0.36 to 4.85 ng/m$^3$ glucan. The lung lavage concentrations of inflammatory markers increased 1.2–3.2 fold in these workers post-shift as compared to pre-shift.

The exact thresholds for adverse health effects due to exposure to endotoxins, glucans and airborne fungi are not known. Milton *et al*. [30] reported declines in lung function in fiberglass workers when exposed to endotoxin concentrations of 4 ng/m$^3$ or greater. Thorn and Rylander [38] noted significantly higher levels of chest tightness and joint pain in houses with over 2 nanograms of glucan per cubic meter. A survey of 18 apartments reported endotoxin concentrations from 0 to 18 ng/m$^3$ and glucan concentrations from 0 to 11 ng/m$^3$ [34]. Higher levels of either glucan (above 2.0 ng/m$^3$) or endotoxin (above 0.2 ng/m$^3$) were associated with fatigue. High glucan levels were associated with irritation of the nose and hoarseness, and high endotoxin levels were associated with cough, breathing difficulties and itchy eyes. Licorish *et al*. [24] reported that exposure to spore extracts equivalent to 1,000 cfu/m$^3$ of *Alternaria* or 35,000 cfu/m$^3$ of *Penicillium* for several hours could severely decrease lung function in several asthmatics.

An Austrian study [26] followed a subset of 34 employees from a composting facility longitudinally over a three year period. Lung function decreased over time but remained within expected values. The concentration of total IgE increased over this time period. A German study of 362 compost workers in 42 composting plants found that asthma, allergic bronchitis, and allergic alveolitis where no more common in the compost workers than in 129 control workers [35, 36]. A study of 1,104 workers in three German compost plants found that respiratory and skin complaints were somewhat more common in exposed *versus* 1,213 non-exposed workers [20].

This study in an outdoor suburban yard waste composting facility in northern Illinois was conducted in response to neighborhood residents' concerns over odors and potential bioaerosol exposures. That year, the facility received approximately 16,000 cubic yards of landscape waste comprised of grass clippings, leaves and tree branches. Leaf volume comprised approximately 35% of this volume and was concentrated over the months of October, November, and December.

## MATERIALS AND METHODS

From September–November 1995, Andersen bioaerosol and airborne dust samples were collected during 10 sampling days at various sites in and around the composting facility. Sampling days included five days in which intense compost activity was undertaken, three days in which moderate pile activity occurred and two days in which the piles were undisturbed by human activity.

Viable fungi and bacteria were collected with Andersen (Grasby-Andersen, 4801 Fulton Industrial Blvd., Atlanta, Georgia, USA, 30336 (404) 691-1910) one-stage N6 viable collectors. A 1/10 horsepower General Electric DC Pump was connected to a portable 12 Volt Interstate Battery to

**Table 3.** Summary of bacteria (Gram-positive, Gram-negative and actinomycetes) concentrations for the 55 off-site (north, south, east and west sites) and the 54 on-site samples taken 1 and 10 meters from the piles.

| Bacteria | 55 off-site samples | | | | 54 on-site samples at 1 and 10 meters | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean cfu/m$^3$ | Median cfu/m$^3$ | Range cfu/m$^3$ | Percent of total bacteria | Mean cfu/m$^3$ | Median cfu/m$^3$ | Range cfu/m$^3$ | Percent of total bacteria |
| Total bacteria | 3,204 | 2,080 | 160-17,600 | 100.0 | 11,879 | 4,520 | 480-78,880 | 100.0 |
| Gram-positive bacteria | 1,523 | 840 | 160-7,436 | 47.8 | 6,738 | 2,458 | 240-43,030 | 55.2 |
| Gram-negative bacteria | 1,664 | 1,171 | 0-11,768 | 52.2 | 5,478 | 2,055 | 240-41,164 | 44.8 |
| Actinomycetes | 94 | 0 | 0-1,189 | 2.9 | 202 | 84 | 0-1,520 | 1.7 |

Note: fenceline values not included in this table.

**Table 4.** Summary of off-site and on-site values for total particulates, endotoxin and glucans.

| | 28 off-site samples | | | | 18 on-site samples | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean ng/m$^3$ | Median ng/m$^3$ | Percent of total dust | Range ng/m$^3$ | Mean ng/m$^3$ | Median ng/m$^3$ | Range ng/m$^3$ | Percent of total dust |
| Total particulates | 98,892 | 84,000 | | 41,000–278,000 | 631,222 | 384,000 | 47,000–1,805,000 | |
| Endotoxin | 0.14 | 0.14 | 0.00014 | 0.01–0.41 | 1.94 | 1.99 | 0.12–6.06 | 0.003 |
| β-1,3- glucans | 0.24 | 0.13 | 0.00024 | 0.01–0.78 | 2.17 | 0.79 | 0.12–14.45 | 0.0034 |

collect 0.0125 m$^3$ of air for Andersen samples. Samples were collected about 0.5 m above ground to correspond with the height of the Kramer-Collins samplers used in this study. The Andersen samplers were loaded with autoclaved soy-casein agar media plates for bacterial samples and malt extract agar media plates for fungal samples as described by Morey *et al.* [31].

On the morning of each sampling day, Andersen samples containing malt extract media for fungi and Andersen samples containing soy-casein media for bacteria were collected at eight sites. The samples collected from these eight sampling sites included: 1) a sample from the north site located 288 m north–north-east of the composting site in a meadow adjacent to suburban homes; 2) a sample from the south site located about 100 m south of the composting facility between the soccer and baseball fields near an adjacent middle school; a 3 m high berm separated the composting pile from these athletic fields; 3) a third sample was taken either at an east site or west site depending upon which sampling location was more downwind relative to the prevailing wind; the east site was located about 290 m east–north-east of the composting facility in a meadow of mixed vegetation; the west site was located about 216 m west–south-west of the compost facility in a back yard adjacent to a suburban house under construction and a golf course; 4) the fourth sample was taken 1 m downwind of compost pile activity; 5) sample five was taken 10 m downwind from the pile; 6) sample six was taken downwind at the fence line of composting operation, 150 m from the center of the site and 75 m from the nearest compost pile; 7) sample seven was taken 10 m upwind of the pile and 8) sample eight was taken upwind at the fence line of the composting facility, 150 m from the center of the site and 75 m from the nearest compost pile. Samples four to eight were collected at locations relative to the section of piles that had been most recently disturbed, at times when no compost pile activity was present. Andersen samples were collected at a flow rate of 0.028 m$^3$/min for 55 seconds to collect 0.025 m$^3$ of air.

When time permitted, the 16 Andersen samplers were unloaded, autoclaved, allowed to cool, re-loaded with fresh media and a second set of eight fungal samples and eight bacterial samples were collected in the afternoon. After collection of airborne particulates containing viable fungi and bacteria, the plates were incubated at 25ºC for 3-5 days until abundant growth was noted. The bioaerosol concentrations in colony forming units per cubic meter (cfu/m$^3$) were calculated by taking an average of the two bioaerosol counts divided by the volume of air sampled. On samples containing 20 or more colonies per plate, a count correction factor was used to account for undercounting of spores due to two or more spores being present in one hole [2].

Fungal colonies were then examined microscopically and classified as to genera [5, 16]. Bacterial isolates were Gram-stained using crystal violet stain, iodine solution, and neutral red solution to determine Gram-negative and Gram-positive bacteria [8]. Total bacteria may not exactly equal the total of Gram-positive and Gram-negative bacteria since these counts were made separately.

Quartz filters were oven-heated to 170ºC for four hours to degrade endotoxin and while still warm were weighed on a Mettler balance H51AR. Dust samples were then collected for 6–8 hours on 20 cm × 25 cm quartz-fiber filters with a high-volume particulate air sampler [25] during the 10 sampling days noted above at the following locations: 1) at the north site (listed above in the section on fungi and

**Table 5.** Summary of Kramer-Collins spore sampling by off-site and on-site sampling locations.

| Fungal spore type | 27 off-site samples | | | | 10 on-site samples | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean spores/$m^3$ | Median spores/$m^3$ | Range spores/$m^3$ | % of total spores | Mean spores/$m^3$ | Median spores/$m^3$ | Range spores/$m^3$ | % of total spores |
| Total Spores | 8,772 | 8,937 | 243-18,276 | 100.00 | 13,451 | 12,894 | 5,223-26,067 | 100.0 |
| *Alternaria* | 244 | 160 | 0-1,002 | 2.78 | 242 | 209 | 0- 916 | 1.80 |
| Ascospores | 411 | 264 | 0-2,081 | 4.69 | 81 | 0 | 0-320 | 0.60 |
| *Aspergillus* and *Penicillium* | 264 | 223 | 0-1,010 | 3.01 | 3,207 | 2,674 | 114-8,682 | 23.64 |
| Basidiospores | 737 | 489 | 0-4,668 | 8.40 | 1,692 | 1,094 | 478-4,235 | 12.58 |
| *Cercospora* | 48 | 0 | 0-1,011 | 0.55 | 124 | 0 | 0-1,081 | 0.92 |
| *Cladosporium* | 4,528 | 3,146 | 86-11,847 | 51.62 | 717 | 270 | 0-3,572 | 5.33 |
| *Epicoccum* | 60 | 48 | 0-234 | 0.68 | 94 | 0 | 0-514 | 0.70 |
| *Fusarium* | 3 | 0 | 0-79 | 0.03 | 0 | 0 | 0 | 0.00 |
| *Helminthosporium* | 0 | 0 | 0 | 0.00 | 18 | 0 | 0-178 | 0.14 |
| *Myxomycetes* | 2 | 0 | 0-20 | 0.02 | 168 | 0 | 0-799 | 1.25 |
| *Nigrospora* | 14 | 0 | 0-131 | 0.16 | 54 | 0 | 0-383 | 0.40 |
| *Periconia* | 7 | 0 | 0- 67 | 0.08 | 0 | 0 | 0 | 0.00 |
| *Pithomyces* | 23 | 0 | 0-131 | 0.26 | 32 | 0 | 0-320 | 0.24 |
| Rusts | 47 | 16 | 0-604 | 0.54 | 138 | 0 | 0-746 | 1.03 |
| Smuts | 151 | 48 | 0-836 | 1.72 | 428 | 352 | 0-932 | 3.18 |
| *Torula* | 18 | 0 | 0-142 | 0.20 | 28 | 0 | 0-280 | 0.20 |
| Unidentified | 2,172 | 2,213 | 114- 4,815 | 24.76 | 6,429 | 4,114 | 2,185-16,854 | 47.80 |

bacteria); 2) at the south site; 3) at the east or west site depending upon which was more downwind of the prevailing wind; 4) at the trailer house located in the middle of the composting facility; and 5) on a personal sampler attached to the worker or next to a worker in a open-cab front end loader. The north, south, east and west sites were collected with a hi-volume sampler which collected air at 1.3 $m^3$/minute. The trailer house sampler was collected with Thomas TA 15-V 1/10 horsepower pump collecting air at 0.045 $m^3$/minute. The personal sampler was a Gillian HFS 113 pump collecting 0.003 $m^3$/minute of air. These particulate samples were used for three measurements: total particulates, endotoxin, and β-1,3-glucans.

After sampling, the filters were heated gently at 40ºC for one hour to remove moisture, weighed on an analytical balance, and frozen prior to analysis for endotoxins and glucans. The dust samples were analyzed for endotoxin levels using the Quantitative Chromogenic Limulus amebocyte lysate assay similar to that described by Webster [41]. Reagents, endotoxin-free water and endotoxin standards were obtained from the Bio Whittaker Inc. (Bio Whittaker, 8330 Biggs Ford Road, PO Box 1027, Walkersville, MD 21793-0127, USA). Endotoxin concentrations (0.10 ng endotoxin per 1 Endotoxin Unit) were expressed in a weight basis with standards provided by Bio Whittaker.

The dust samples were analyzed for β-1,3-glucans concentrations by a Limulus amebocyte "G" factor assay similar to that described by Goto *et al.* [18]. Reagents and β-1,3-glucans standards from yeast were obtained from Seikagaku Corporation (Seikagaku, 1-5, Nohonbashi-honcho 2-chome, Chuo-ko, Tokyo 103, Japan).

Levels of the Asp f1 protein (obtained from the mycelium of *Aspergillus fumigatus*) were analyzed by the sandwich ELISA method developed by Arruda *et al.* [4].

For the determination of spore concentration, the Kramer-Collins spore sampler was used. This is a suction sampler designed to measure volumes of air through a narrow inlet past a rotating drum [17, 22]. The 15.2 cm diameter rotating drum is covered with a 1.88 cm transparent tape which is coated with silicone grease as a particle trapping medium. The rotation rate of the drum can be adjusted to rotate the drum once over several hours or several days. Air is drawn through the sampler using a high volume pump. A wind vane is attached to the sampler body to ensure that the sampler inlet is always facing into the wind. After the sampling is completed the transparent tape is transferred from the drum onto a microscope slide for examination.

Continuous 24-hour sampling was performed at the site from 1 September–27 November. A spore sampler was placed 6 m north of the northern edge of the compost piles and 3.7 m above ground. The sampler was set to rotate the

**Table 6.** Concentrations of Asp f1 protein above the detection limit.

| Location | Activity | Wind direction | Date | Asp f1 ng/m$^3$ |
|---|---|---|---|---|
| Off-site: north field | None | North | 20-9-1995 | 0.61 |
| On-site: personal sample | Turning | South-east | 2-10-1995 | 22.17 |
| On-site: compost house sample | Turning | South-east | 2-10-1995 | 1.14 |
| Off-site: south field | Turning | North | 18-10-1995 | 0.18 |
| On-site: compost house sample | Turning | North-west | 13-11-1995 | 0.84 |
| Off-site: south field | Turning | North-west | 13-11-1995 | 0.63 |

**Table 7.** Mean off-site concentrations by wind direction.

| Bioaerosol | Downwind | | | | Upwind | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of samples | Mean | S.D. | Range | Number of samples | Mean | S.D. | Range |
| Viable bacteria (cfu/m$^3$) | 11 | 3,967 | 3,078 | 160-9,040 | 9 | 2,582 | 1,882 | 720-6,560 |
| Viable fungi (cfu/m$^3$) | 11 | 4,378 | 4,318 | 160-14,040 | 9 | 3,329 | 3,781 | 80-10,840 |
| Total particulates (µg/m$^3$) | 10 | 100 | 50 | 43-216 | 8 | 135 | 84 | 50-278 |
| Total spores per m$^3$ | 10 | 8,364 | 6,061 | 307-18,276 | 8 | 8,164 | 4,543 | 243-13,233 |
| Endotoxin (ng/m$^3$) | 10 | 0.158 | 0.104 | 0.058-0.413 | 8 | 0.141 | 0.117 | 0.010-0.359 |
| β-1,3-glucans (ng/m$^3$) | 10 | 0.177 | 0.172 | 0.040-0.530 | 8 | 0.266 | 0.279 | 0.010-0.780 |

drum once every 16 days a 24-hour sample therefore consisted of a segment of about 3 cm of tape. The sampler flow rate was 8 liters per minute. A relatively low flow rate was chosen because the very dusty conditions on site would overload the sampling medium. Even at 8 liters per minute, some segments of the on-site samples were loaded with too much dust and could not be analyzed.

Off-site sampling was performed on 6, 15, 20, 28 September, 2, 4, 18, 23 October and 6, 13 November. Sample durations were 4–7 hours. The samplers were mounted on poles about 0.75 m above the ground, 150 m from the center of the site and 75 m from the nearest compost pile. The flow rate used was 30 liters per minute. The off-site samplers were adjusted to rotate the sampling drum once every seven days, so the samples fitted onto segments of tape less than 2.5 cm long.

Data on temperature, wind direction, and wind velocity were collected from an on-site meteorological station maintained by the site operator. These data were downloaded from an on-site personal computer to a Dbase file. Wind speed and temperature were not available for 23 October 1995.

Descriptive summary statistics (mean, median, range, percents) of study variables were generated using PC-SPSS 6.1 and SAS. Statistical analysis of differences in mean and median concentrations by sampling location, wind direction, and on-site activity for selected bioaerosol constituents was performed using ANOVA (analysis of variance) and the Kruskall-Wallis test (for non-parametric data).

## RESULTS

Table 1 summarizes Andersen sampling results for viable fungi and bacteria at each of the sampling sites. The highest fungal concentrations were found in the wooded wetland region just east of the composting facility. In contrast, mean bacterial concentrations were highest 1 m downwind from the piles and second highest values were found 10 m downwind from the pile. Table 2 summarizes the major fungal genera identified in on-site and off-site samples. Mean viable fungal concentrations were more than twice as great off-site as on-site. The most common fungi collected included *Aspergillus, Penicillium, Cladosporium. Alternaria,* yeasts, *Rhizopus* and *Epicoccum*, with concentrations exceeded 1,000 cfu/m$^3$ in some cases. Table 3 summarizes concentrations of bacteria on-site and off-site. In contrast to the results for fungi, bacterial concentrations were much higher on-site *versus* off-site.

Mean concentrations of total dust, endotoxins and β-1,3-glucans were also much higher on-site than off-site (Tab. 4). Table 5 reports Kramer-Collins spore counts for on-site and off-site samples. Mean total fungi spore counts were somewhat higher on-site than off-site, but this was not consistent for all spore types. The most prominent fungi collected by Kramer-Collins were *Cladosporium, Aspergillus/Penicillium* and basidiospores. Table 6 shows the six particle samples where Asp f1 was above the analytical detection limit. Five out of 23 (22%) dust samples collected on turning days had Asp f1 levels about the

**Table 8.** Mean concentrations by level of activity at compost pile.

| Bioaerosol | Activity | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | None (2 days) | | | | Moderate (3 days) | | | | Turning (5 days) | | | |
| | Number of samples | Mean | S.D. | Range | Number of samples | Mean | S.D. | Range | Number of samples | Mean | S.D. | Range |
| Viable bacteria: off-site(cfu/m$^3$) | 6 | 1,380 | 325 | 960-1,960 | 9 | 3,911 | 2,312 | 1,400-8,960 | 15 | 3,715 | 2,677 | 160-9,040 |
| Viable bacteria: on-site(cfu/m$^3$) | 10 | 3,232 | 3,103 | 840-11,480 | 14 | 18,414 | 15,122 | 3,240-47,360 | 25 | 8,278 | 10,895 | 1,200-55,640 |
| Viable fungi: off-site(cfu/m$^3$) | 6 | 2,467 | 2,102 | 520-5,920 | 9 | 13,920 | 30,252 | 800-94,320 | 15 | 10,167 | 16,228 | 80-65,320 |
| Viable fungi: on-site(cfu/m$^3$) | 10 | 2,788 | 2,152 | 480-6,080 | 14 | 3,777 | 2,828 | 1,200-11,720 | 25 | 10,937 | 15,993 | 80-61,520 |
| Total particulates: off-site (µg/m$^3$) | 6 | 97 | 32 | 57-132 | 8 | 126 | 81 | 59-278 | 14 | 84 | 53 | 41-244 |
| Total particulates: on-site(µg/m$^3$) | 3 | 1,044 | 859 | 63-1,645 | 6 | 841 | 665 | 56-1,805 | 9 | 342 | 250 | 47-800 |
| Total spores/m$^3$: all-sites | 7 | 9,780 | 3,637 | 4,210-13,002 | 11 | 8,526 | 7,400 | 1,666-25,531 | 19 | 9,929 | 5,180 | 243-18,276 |
| Endotoxin (ng/m$^3$) all-sites | 9 | 0.204 | 0.190 | 0.010-0.648 | 14 | 0.894 | 1.649 | 0.068-6.057 | 23 | 1.073 | 1.511 | 0.027-4.624 |
| β-1,3-glucans (ng/m$^3$) all-sites | 9 | 0.624 | 1.024 | 0.040-3.270 | 14 | 0.524 | 0.799 | 0.060-3.150 | 23 | 1.426 | 3.365 | 0.010-14.460 |

detection limit, as compared to 0 of 14 (0%) samples taken on moderate activity days and 1 out of 9 (11%) taken on no activity days. Table 6 shows that the highest Asp f1 values were obtained on 2 October 1995 from the personal sample (22 ng/m$^3$) and compost house on-site sample (1.14 ng/m$^3$).

Table 7 shows the off-site measurements sorted by wind orientation. The Table shows that off-site concentrations of viable bacteria, viable fungi, spores and particulate matter are similar when measured upwind and downwind of the facility.

Table 8 reports concentrations for days of no activity, moderate activity and compost pile turning. The Table shows that on-site viable bacterial ($p < 0.001$), fungal concentrations ($p = 0.003$) and endotoxin (all-sites) ($p = 0.004$) are higher on days with site activity. The table also shows that off-site viable bacteria ($p = 0.001$) and fungi ($p = 0.057$) are higher on days with site activity. In contrast, total particulate concentrations on-site were highest during no activity, however, this could have been due to the fact that the facility operators were less likely to turn the compost under windy conditions. These data represent strong evidence of the emissions of bioaerosols from the movement of compost piles.

## DISCUSSION

One of the most prominent findings of this study was the high level of viable bacteria emitted by the composting facility. Mean bacterial concentrations (in cfu/m$^3$) downwind from the piles were 19,044 at 1 m, 9,793 at 10 m and 5,975 at fence line. Pile activity such as turning was associated with significantly higher bacterial concentrations both on- and off-site.

Daily activities at the sampling sites were also associated with large changes in morning *versus* afternoon concentrations of viable fungi and bacteria. For example, during the midday of 28 September 1995, the meadow grass in the north sample was cut by lawnmowers. Morning concentrations of viable fungi and bacteria (in cfu/m$^3$) were only 160 and 480 respectively, but they jumped to 15,040 and 17,600 in the afternoon after mowing.

The higher levels of bacteria seen around the composting site, and especially higher levels of bacteria during periods of activity are consistent with several other composting studies. Jager *et al.* [21] reported that airborne bacteria during compost shredding periods ranged from 21,201–84,806 cfu/m$^3$ as compared to 1,979–3,869 during quiet periods at the site and only 495–1,312 cfu/m$^3$ at upwind sites. Folmsbee and Stewart [15] reported mean bacteria concentrations of 5,059 cfu/m$^3$ at 30 m downwind as compared to 1,000 cfu/m$^3$ several km downwind. Reinthaler *et al.* [33] reported median airborne bacterial concentrations of 4,500 cfu/m$^3$ at a site 3 m from composting windrows, but only 120 to 450 cfu/m$^3$ at five sites 200–700 m from the composting facility.

Fungal concentrations (cfu/m$^3$) on-site were significantly ($p = 0.003$) higher during turning periods (10,937) than during periods of no site activity (2,788). The Jager *et al.* [21] study also noted that fungal concentrations (cfu/m$^3$) at

composting sites were much higher during shredding periods (medians of 5,151–19,064) and that fungal concentrations were fairly similar on-site during quiet periods (106–777) and off-site (141–315).

While off-site (*vs* on-site) concentrations of total spores and total viable fungi were not significantly higher during periods of activity, it is important to note that the area surrounding the facility is wooded with wetland areas and a river. Had the composting site been surrounded by a dry or paved area, the observed emission patterns might well be different. The 3 m high berm at the south fenceline of the composting site may partially block bioaerosol transport to the athletic fields just south of the composting facility.

The three most prominent fungi found in the viable and non-viable sampling were *Aspergillus*, *Penicillium* and *Cladosporium*. This is similar to the Gottlich *et al.* study [19]. Fischer [12] noted *Aspergillus* and *Penicillium* dominated the fungal spores from indoor composting facilities. Additional speciation of the fungi might also have yielded useful data.

A few of the off-site samples contained viable *Alternaria* exceeding the 1,000 cfu/m$^3$ limit shown to worsen asthma by the Licorish *et al.* studies [24]. However, since mean *Alternaria* concentrations are higher off-site than on-site and since much of the area surrounding the compost site is wooded and wet, the compost facility is probably not a major source of *Alternaria* spores.

Some of the on-site dust samples contained more than the 4 ng/m$^3$ endotoxin level shown to adversely affect lung function in the Milton *et al.* study [30]. In addition, total particulate matter was higher on-site (631 µg/m$^3$) as compared to off-site (99 µg/m$^3$). To reduce exposure to dust and dustborne endotoxin and glucans, workers at the facility should use 95% efficiency dust masks in particular when performing dusty tasks. In addition, dust control measures such as wetting the compost should be employed to reduce dust generation from site operations.

Although this study collected 288 Andersen samples, 45 airborne dust samples and 38 Kramer-Collins samples, the normally high variability of bioaerosol concentrations limits the scope of this study to detect statistically significant differences. The Andersen bioaerosol sampler used in this study has two major limitations: 1) it does not detect hyphal fragments, spores, and vegetative bacterial cells which are non-viable on the malt extract and soy casein media; such hyphal fragments and non-viable spores or cells may still cause adverse health effects in humans); and 2) Andersen sampling collects only a small volume of air for only a short time. Short averaging-time samples are inherently highly variable. The major limitations of the Kramer-Collins total spore counter are: 1) it is hard to identify all fungi by visual examination of spores as opposed to the entire fungus (for example *Penicillium* and *Aspergillus* spores look alike and cannot be speciated); and 2) the sampler collects particles by impaction and therefore, does not collect smaller spores such as *Aspergillus/Penicillium* as effectively as larger spores such as *Alternaria*. This differential collection may account for the much higher percentage of *Penicillium* and *Aspergillus* colonies in the Andersen counting as compared to the Kramer-Collins sampling.

Development of methods to measure long-term concentrations of fungal spores and hyphal fragments from composting and other sources are needed. Recent methods to analyze fungal proteins, DNA or fungal metabolites in dust which include enzyme-linked immunosorbent assays (ELISA) [4], Polymerase Chain Reaction (PCR) [1], flurochromic substrates [27] and detailed analysis of mycotoxins [39] are promising alternatives to the methods used in this study. This work is probably the first study which measured Asp f1 levels in and around composting facilities. Work is also underway to detect and speciate viable/non-viable bacteria and fungal spores by laser desorption [9, 42].

Since bacteria generation is significant at the composting sites, speciation of bacteria would also be very useful. Recently Anderson and coworkers have developed methods to speciate bacteria in indoor dust [3]. Additional prospective health studies of workers and neighboring residents are also needed to help elucidate possible adverse health effects of composting.

## CONCLUSIONS

The presented data demonstrate that the compost piles were a significant source of on-site concentrations of total bacteria, Gram-positive bacteria, Gram-negative bacteria, and actinomycetes. The data suggest that the compost piles were also a source of on-site concentrations of total spores, *Aspergillus/Penicillium* spores, total particulate matter, endotoxin, and β-1,3-glucans.

Workers at the facility had the highest exposures to total particulate matter, endotoxin, and β-1,3-glucans. The peak exposure to endotoxin was sufficient to warrant use of respirators, especially during periods of pile activity that lead to dust generation.

The impact of the compost facility on off-site bioaersol concentrations was not as apparent. It is important to note that the facility was located in a wooded area with a nearby river and wetland, which undoubtedly contributed to bioaerosol concentrations in local ambient air. The data indicate that the facility was probably not a significant source of off-site exposure to total spores and total viable fungi relative to local background concentrations. Because we did not speciate the viable fungi, the lack of a statistically significant demonstration of off-site emission of total viable fungi does not preclude the possibility that individual species, such as *Aspergillus fumigatus,* may have been emitted to off-site locations. Moreover, the high variability of background bioaerosol concentrations limits the scope of the study to detect significant differences, especially for Andersen samples which have a short sampling time of only 55 seconds. Measurements of total spores, particulates, endotoxin, and β-1,3 glucans are likely to be more stable due to the considerably longer sampling time (6–8 hours). The significant increase in off-site

concentrations of bacteria during periods of site activity suggests a possible association between the on-site and off-site bacterial concentrations. This association, however, was not supported by comparisons of off-site upwind *vs* downwind bacterial concentrations.

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