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Inhalable dust as a marker of exposure to airborne biological agents in composting facilities

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ABSTRACT

Objectives: Industrial composting is associated with high levels of worker exposure to bioaerosols. Measurement of airborne microorganisms and endotoxin is complex and the related cost is high. The objective was therefore to examine whether dust measurement could be used as a marker of exposure to bioaerosols in composting facilities.

Methods: A dataset of 110 measurements carried out in eight sludge composting plants was explored. Mixed-effects models were constructed to explain between-site and within-site variability in concentration of endotoxin and culturable mesophilic bacteria, mesophilic moulds and thermophilic actinomycetes in air. Fixed-effects variables were inhalable dust concentration, the season, the outdoor/indoor location of sampling and the process area.

Results: The level of dust was a highly significant determinant of concentration for all biological agents. Within-site variability was always larger than between-site variability. The proportion of within-site variability explained by determinants was 68%, 65%, 56% and 60% for endotoxin, bacteria, moulds and actinomycetes, respectively. Inclusion of dust in the final model resulted in an increase of 24, 20, 12 and 17 points of percentage within-site variability, respectively. Inclusion of season resulted in an increase of 9, 12, 12 and 15 points, respectively. Within-site variability was less influenced by outdoor/indoor location and process area, except for moulds.

Conclusion: Dust was the factor that most influenced within-site variability in endotoxin and culturable bacteria concentration. Measurement of dust can efficiently assist decision making for prevention measures against endotoxin and bacteria in sludge composting plants. Our results are not as conclusive for actinomycetes and especially for moulds.

1. Introduction

Over recent decades, exposure to airborne biological agents (i.e., bioaerosols) in the workplace has emerged as a major hygiene issue in several industrial activities, such as industrial farming and agriculture, the wood industry, microbial enzyme production, food processing, the metalworking industry, wastewater treatment, use of biofuels for energy, and waste management (Douwes et al., 2003; Dutkiewicz, 1997; Eduard et al., 2012; Oppliger and Duquenne, 2015; Rylander and Jacobs, 1994). Bioaerosols are organic dusts of plant, animal or microbial origin. They include living and non-living microorganisms, as individual microorganisms or as aggregates, fragments and products of microorganisms such as bacterial endotoxin, β(1-3)-D glucans, allergens, mycotoxins and any of the above carried on other particles (ACGIH, 1999). The main route of exposure is inhalation, and potential health effects are infection, immune-allergic respiratory diseases and the inflammation of airways from non-allergic mechanisms (ACGIH, 1999; Douwes et al., 2003; Rylander and Jacobs, 1994).

According to the 1999 European Landfill Directive (Council Directive 1999/31/EC), processes are being developed that ensure the recycling and energy recovery of biodegradable fractions of waste as an alternative to landfill disposal. The development of biodegradable waste recycling leads to an increase in the amounts of decaying organic materials handled and situations whereby workers are potentially exposed to bioaerosols. Water activity, temperature and storage duration encourage the growth of bacteria and fungi in the organic fraction of waste and in cellulosic substrates such as paper and cardboard that are disposed of as commercial and industrial waste (Pahren, 1987; Palmisano and Barlaz, 1996; Schlosser et al., 2015; Searl, 2008). At waste management facilities, such as sorting plants, mechanical biological

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treatment (MBT) plants and composting plants, waste handling, mechanical agitation, vehicle movement and cleaning and maintenance operations lead to particles being suspended in the air. These particles are made of or contain microorganisms and associated fragments and products (Degois et al., 2017; Searl, 2008; Swan et al. 2003; van Kampen et al, 2014; Wéry, 2014). Other components of airborne particles may be inorganic compounds, such as plastics and silica, or other biological agents such as wood dust.

Epidemiological evidence of increased health risks among waste industry workers owing to bioaerosol exposure is limited (Gladding et al., 2003; Sigsgaard et al., 1994; van Kampen et al., 2016). However, there is strong qualitative evidence that links occupational exposure to bioaerosols in the waste industry to adverse effects on health including long-term respiratory disease, notably in the composting field (Schlosser et al., 2009; Searl, 2008). Moreover, in order to protect local communities, there is a trend towards controlling odours and dust nuisance by enclosing facilities. Conducting operations indoors may lead to increased levels of worker exposure to dust and bioaerosols. These key points highlight the need for bioaerosol-related health risk management in composting facilities and other waste management plants. To date, no regulatory limits have been set for occupational exposure to endotoxins, bacteria and fungi (Pearson et al., 2015, Walser et al., 2015). However, measurement results can be compared with health-based or non-health-based guidelines that can be useful for risk management (Balty et al., 2015; Eduard, 2009, Goyer et al., 2001; Health Council of the Netherlands, 2010; Malmros et al., 1992). Measurement of airborne microorganisms and endotoxin requires experienced personnel and the related cost is high. Moreover, bioaerosol sampling procedures are not yet completely standardized (Duquenne et al., 2013; Eduard et al., 2012; Spaan et al., 2008a). On the other hand, measurement of dust in the air using gravimetric analysis is simple, inexpensive and does not require specific expertise. Analysis can easily be carried out on sites by health and safety technicians. Consequently, there are grounds to wonder whether measurement of inhalable dust may be used as a marker for bioaerosol exposure assessment at the workplace.

The main goal of this study was to examine to what extent inhalable dust concentration explains variations in endotoxin and culturable microorganism concentrations in the air of composting facilities. A set of measurement data from sampling campaigns in sludge composting plants was explored using mixed-effects regression models. These models estimate both the effect of dust and other factors on the biological agent concentration and their influence on the between-site and within-site variability in concentration. This study, which to our knowledge is the first of its kind, will contribute towards informing health and safety managers, composting site operators and labour inspectorates about the possibility and limitations of using dust measurement for bioaerosol exposure assessment and control in sludge composting facilities.

2. Methods

2.1. Selection of sites

The measurement results included in this study are derived from air sampling campaigns in composting plants carried out between 2007 and 2010 as part of research projects (Schlosser et al., 2009, 2012) or on-site technical support. Eight composting facilities were selected for this study, seven in France and one in Spain. These sites are all sewage sludge composting facilities, and they have different characteristics that make them representative of the majority of installations in Europe (Table 1). One site is totally enclosed, five sites are partially confined and two are open-air sites. The bulking agent is most often made up of crushed pallets and/or wood; one site receives green waste whilst another site receives wood chips and bark. Thermophilic aerobic decomposition of feedstock mixtures is carried out in open boxes, tunnels or windrows. The material ventilation process is either static, by suction or blowing, or consists in turning windrows once a week with the aid of a turning machine pulled by a tractor. At each site, ventilation was either natural or a general mechanical ventilation system. None of the processes were equipped with a local exhaust ventilation system.

2.2. Sampling strategy

At 6 of the 8 sites (A, B, C, D, F and G), two air sampling campaigns were carried out, one in the warm season (from April to September) and one in the cold season (from October to March). At site E, samples were only taken during the warm season, whilst at site H, samples were only taken during the cold season. Stationary sampling and task-based personal sampling were carried out at each of the sites. Some personal sampling was carried out when workers were operating machinery (loaders, turning machines, tractors). These samples were excluded from this study because the concentrations of dust and biological agents inside the cabin were influenced by the filtration system fitted to the engine. This change in concentration can be different depending on particle size and may therefore have introduced bias in data analysis (Schlosser et al., 2012). Other measurements for which the process area varied during sampling have also been excluded.

For all stationary and personal measurements, the simultaneous collection of dust and biological agents was performed using two CIP 10 aerosol samplers (Tecora, France) equipped with the inhalable fraction selector, which is described in other studies (Görner et al., 2006; Nieguitsila et al., 2011; Schlosser et al., 2012). Briefly, this sampler uses the rotative cup technique with rotation maintaining a flow rate of 10 L min^{-1}. For dust measurement, the cup of one of the two samplers was equipped with polyurethane foam. For the measurement of microorganisms and endotoxin (referred to as biological agents in the text), the cup of the other CIP 10 was filled with 2 mL of pyrogen-free sterile water (Versol, Agulant Laboratory) containing 0.05% Tween 20 surfactant (Polyoxyethylen sorbitan monolaurate, Merck). The cup was rinsed three times to facilitate particle recovery. The physical collection efficiency (i.e., the ability of the sampler to capture particles) of CIP-10 equipped with the inhalable fraction selector is similar to that of many single-stage impactors and is estimated to be 50% for particles with an aerodynamic diameter of 1.8 μm and more than 95% for particles exceeding 2.8 μm (Görner et al., 2006). Furthermore, the shielded multidirectional sampling head of the CIP 10 limits sampling of projected coarse particles.

A total of 110 pairs of air samples were included in the study, comprising 92 stationary samples and 18 personal samples taken during tasks outside the vehicle cab. For each sampling, the process area of the stationary sampling point or associated with the task being performed during sampling was noted. These areas included the feedstock mixing area (17% of the observations), the thermophilic aerobic decomposition area (24%), the screening area (40%) and the maturation and/or storage area (19%). All processes were in operation during the sampling runs. The outdoor or indoor location of the sampling point or the task being performed during sampling was also recorded. Sampling times ranged from 30 to 60 min for stationary samples and from 20 to 40 min for personal samples. Calibration of the CIP 10 samplers was verified in the field by measuring the rotational speed of the cup using an optical tachymeter (Tecora).

Temperature, relative humidity and air velocity measurements were taken throughout the sampling day using Kimo-VT200® and