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## An analysis of employee exposure to organic dust at large-scale composting facilities.

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**Abstract.** The occupational health implications from exposure to dust, endotoxin and 1-3  $\beta$  Glucan at commercial composting sites are uncertain. This study aims to establish employee exposure levels to inhalable and respirable dust, endotoxin and 1-3  $\beta$  Glucan during various operational practices in the composting process. Personal samples were collected and the inhalable and respirable dust fractions were determined by gravimetric analysis. Endotoxin concentrations were determined using a Limulus Amebocyte Lysate assay (LAL). 1-3  $\beta$  Glucan levels were estimated using a specific blocking agent to establish the contribution that these compounds gave to the original endotoxin assay. Employees' exposure to dust was found to be generally lower than the levels stipulated in the Control of Substances Hazardous to Health Regulations (COSHH) 2002 (as amended), (median inhalable fraction 1.08 mg/m<sup>3</sup>, min 0.25 mg/m<sup>3</sup> max 10.80 mg/m<sup>3</sup>, median respirable fraction 0.05 mg/m<sup>3</sup>, min 0.02 mg/m<sup>3</sup>, max 1.49 mg/m<sup>3</sup>). Determination of the biological component of the dust showed that employees' exposures to endotoxin were elevated (median 31.5 EU/m<sup>3</sup>, min 2.00 EU/m<sup>3</sup>, max 1741.78 EU/m<sup>3</sup>), particularly when waste was agitated (median 175.0 EU/m<sup>3</sup>, min 2.03 EU/m<sup>3</sup>, max 1741.78 EU/m<sup>3</sup>). Eight out of 32 (25%) of the personal exposure data for endotoxin exceeded the 200 EU/m<sup>3</sup> temporary legal limit adopted in the Netherlands and thirteen out of 32 (40.6%) exceeded the suggested 50 EU/m<sup>3</sup> guidance level suggested to protect workers from respiratory health effects. A significant correlation was observed between employee inhalable dust exposure and personal endotoxin concentration ( $r = 0.728$ ,  $p < 0.05$ ) and also personal endotoxin exposure and 1-3  $\beta$  Glucan concentration ( $r = 0.817$ ,  $p < 0.05$ ). Further work is needed to explore the possibility of using inhalable dust concentration as a predictor for personal endotoxin exposure. The general dust levels stipulated in the COSHH Regulations 2002 (as amended) are inadequate for managing the potential health risks associated with endotoxin exposure at composting sites. Employee exposure levels and dose-response disease mechanisms are not well understood at this present time. Consequently, in light of this uncertainty, it is recommended that a precautionary approach be adopted in managing the potential health risks associated with inhalation of organic dusts at composting sites.

### 1. Introduction

The European Landfill Directive (EC/31/1999) and the implementation of subsequent more stringent waste strategies in the UK require at least 45% of biodegradable waste to be diverted from the traditional

practice of landfill, by 2015. The proliferation of commercial composting is already underway in the UK and composting rates have risen from 6% in 1995/1996 to 31% in 2006/07 [1,2].

There is also a trend appearing for larger, centralized composting facilities such as in-vessel composters (IVC) and Mechanical Biological Treatment (MBT) technologies to be utilized in an attempt to achieve these diversion targets [2]. These newer composting technologies are most commonly sited indoors to minimize environmental impacts such as odours, bioaerosol emissions and the attraction of vermin. The occupational health implications of conducting composting operations indoors are poorly understood. One particular area of concern is employees' exposure to bioaerosols which at this present time is poorly characterised. It is unclear whether indoor composting processes have the potential to expose site workers to higher concentrations of organic dust than more traditional 'open – windrow' processes that have more commonly been used.

Bioaerosols are defined as a collection of aerosolised biological particles such as bacteria, fungi and protozoa, cell components and fragments of cells [3-10].

The concern regarding bioaerosols from composting activities arises because of their potential to cause adverse health effects in employees and the public living in close proximity to such facilities. These adverse effects can potentially occur in susceptible individuals from exposure to the micro-organisms associated with the composting process and can elicit an adverse response by infection, allergy or an adverse response to toxins [11].

The effects of exposure to organic dust on respiratory health may lead to or exacerbate a number of distinct identifiable conditions including aspergillosis in immunocompromised individuals [6,7]; allergic rhinitis and asthma [12-14]; extrinsic allergic alveolitis (Farmer's Lung) [15] where prolonged (usually occupational) exposure occurs; chronic obstructive pulmonary disease (COPD) [16-20], toxic pneumonitis /Organic Dust Toxic Syndrome (ODTS) [17,21], upper airway irritation/ mucous membrane irritation [20, 22-24] and an accelerated decline in Forced Vital Capacity (FVC%) [20].

The biological hazards associated with bioaerosol liberation from composting activities are fairly well defined and include fungi, bacteria, in particular actinomycetes, endotoxin and 1–3  $\beta$  glucans [25].

### 1.1. Fungi

Fungi, in particular *Aspergillus fumigatus* have the ability to degrade cellulose and hemicelluloses and are therefore particularly important to the composting process. It is however an allergenic fungus and can cause aspergillosis in immuno-compromised individuals [17,22]. 1-3  $\beta$  Glucan present in the cell wall of fungi has been associated with an increased prevalence of atopy and decreased lung function [26,27].

### 1.2. Bacteria

Whilst respiratory infection from bacteria is unlikely to be a significant hazard [28]. Endotoxin, the lipopolysaccharide portion of the outer layer of the cell walls of gram-negative bacteria, is known to cause acute illness such as flu-like symptoms and Organic Dust Toxic Syndrome (ODTS), chronic exposure has been associated with chronic pulmonary inflammation leading to chronic bronchitis and reduced lung function [29]. Actinomycetes are gram positive bacteria and thermophilic species thrive in wet compost at temperatures between 30 and 60 °C. Thermophilic actinomycetes are known respiratory allergens and are primarily responsible for occupational diseases such as Farmer's Lung and Mushroom Workers lung [7].

Even though the organisms that predominate throughout the composting process have been identified, it is extremely difficult to obtain a concise characterisation of bioaerosol emissions from composting activities. The existence and concentration of individual species associated with the composting process is highly variable and heavily dependant on a number of factors. These include, the nature of the material being composted, individual bioaerosol properties, the temperature and moisture content of the compost,

process design, site operations such as turning, shredding and screening, geographical, topographical and meteorological conditions and whether the process is enclosed or carried out in the open air [28,30].

At present the literature available to determine the potential risks to employees' health from bioaerosol exposure is not sufficiently exhaustive or conclusive. A large proportion of employee exposure studies have utilised static air sampling methodologies which have limited relevance to actual employee exposures in the context of the current regulatory framework for inhalation of inhalable and respirable dust. More significantly, a large number of the studies undertaken to date have focused solely on the enumeration of viable organisms liberated from the composting activities. It has been suggested that the culturable or viable component of bioaerosol emissions may be less than 10% of the total bioaerosol release [31-33]. Therefore, the assessment of viable organisms alone, provides a considerable under-estimation of personal exposure and the potential risks to employees' health as cell components and fragments are known to elicit adverse health outcomes in exposed individuals [24]. Bacterial endotoxin and 1-3  $\beta$  Glucan have been associated with the development of respiratory symptoms in a number of occupational environments [34] and have been measured in order to provide an indication of the biological composition of employees' exposure to organic dust at composting facilities.

## 2. Managing the occupational risks from organic dust exposure

Regulation 2 of the Control of Substances Hazardous to Health Regulations (COSHH) 2002 (as amended) define 'dust' as a 'substance hazardous to health' when present in concentrations in excess of 10mg/m<sup>3</sup> for inhalable dust and 4mg/m<sup>3</sup> for respirable dust. It has been suggested that these general dust levels are unsuitable for managing the occupational risks posed by dusts containing biological material because of their increased toxic potential [35].

Currently in the UK there are no Workplace Exposure Limits for endotoxin and 1-3  $\beta$  Glucan. Guidelines for 'no-effect' levels for environmental endotoxin have been suggested by Rylander [35] and are presented in Table 1.

**Table 1.** Guidelines for 'no-effect' levels for environmental endotoxin.

Disease	ng/m <sup>3</sup> <sup>a</sup>
Toxic pneumonitis	200
Airways inflammation	10
Systemic effects	100

<sup>a</sup> 1ng/m<sup>3</sup>  $\equiv$  10 EU/m<sup>3</sup>

Rylander [35] also reports that a level for 1-3  $\beta$  Glucan of 10 ng/m<sup>3</sup> and above may give rise to health effects similar to those witnessed with endotoxin exposure such as airway inflammation, fatigue and headache.

The Dutch Expert Committee on Occupational Standards of the National Health Council [36] proposed a temporary legal limit of 200 EU/m<sup>3</sup> and a guidance limit of 50 EU/m<sup>3</sup> over an 8 hour exposure period for endotoxin. No similar limit has been suggested for 1-3  $\beta$  Glucan.

This study investigates the impact of operational practices on bioaerosol liberation and employee exposure in four large-scale commercial composting sites. Work on this project is ongoing and the results presented in this paper detail the work conducted to date.

### 3. Methods

Monitoring was undertaken at two open windrow sites, an in-vessel composting facility and an enclosed windrow facility in order to establish the impact that indoor composting activities have on employee exposure compared to those undertaken in the open air.

Bioaerosol liberation from composting activities are influenced by waste composition, moisture content and meteorological conditions [30,37]. Consequently, monitoring was undertaken at each site three times per year during January – March, April – June and July – September to determine the impact of seasonal variation on employee exposure. No monitoring was undertaken during October – December as site operations were limited at this time.

Job Exposure Matrices (JEM) were completed for each employee and the predominant work activity was coded into one of the following predominant work activities;

1)Manual sorting of waste, 2)Shredding, 3)Turning, 4)Screening. Analysis was undertaken to investigate the impact of these operational practices on employee exposure.

A total of 32 personal samples were taken and the inhalable and respirable fraction, endotoxin and 1-3  $\beta$  Glucan was determined. 67 static samples were also taken to evaluate the working environment of employees and analysed for the inhalable fraction, endotoxin and 1-3  $\beta$  Glucan.

Inhalable and respirable dust was sampled in accordance with MDHS 14/3 [38]. Three weighing room blanks were used as laboratory controls for the gravimetric analysis and one additional set of inhalable and respirable samples were left unexposed as field controls. Sampling was performed using Casella Apex Pro constant flow pumps, set to run for 4 hours, in combination with IOM inhalable and Higgins-Dewell cyclonic respirable sampling heads, set at 2.0 l min<sup>-1</sup> and 2.2 l min<sup>-1</sup> respectively and fitted with Whatman GF/A glass fibre filters. Pumps were calibrated before and after sampling and the results extrapolated to an 8 –hour time weighted average (TWA) to enable comparisons with the regulatory levels to be made. The dust concentrations were determined by gravimetric analysis in accordance with MDHS 14/3 [38]. Following gravimetric analysis of the dust, extraction and analyses for endotoxin was performed as previously described [24]. Extraction for endotoxin was performed in 10ml of 0.05% Tween-20 in pyrogen free water. Each sample tube was then placed on a Stuart SB3 Rotator and spun at 25 rev/min for one hour. Following the washing process the sample tubes were spun in a centrifuge at 3000 rpm for 10 minutes. Endotoxin levels were determined, in supernatant, by a chromogenic kinetic Limulus Amebocyte Lysate (LAL). 1-3  $\beta$ -Glucan levels were estimated using a specific blocking agent to establish the contribution that these compounds gave to the original endotoxin assay [39].

### 4. Results

#### 4.1. Dust

Employees' exposure to dust was found to be generally low (median inhalable fraction 1.08 mg/m<sup>3</sup>, min 0.25 mg/m<sup>3</sup> max 10.80 mg/m<sup>3</sup>, median respirable fraction 0.05 mg/m<sup>3</sup>, min 0.02 mg/m<sup>3</sup>, max 1.49 mg/m<sup>3</sup>). Only one of the 32 personal samples exceeded the 10mg/m<sup>3</sup> level stated in the COSHH Regulations and none of the respirable samples exceeded the 4 mg/m<sup>3</sup> COSHH level. Employees' exposures were increased when waste was being agitated but no statistically significant difference was observed between the operational practices of sorting, shredding, turning and screening.

The static dust samples showed extensive variation (median inhalable fraction 0.66 mg/m<sup>3</sup>, min 0.01 mg/m<sup>3</sup> max 172.42 mg/m<sup>3</sup>). Indoor static inhalable dust levels were significantly higher than outdoor static levels (p<0.05 Mann-Whitney *U*-Test).

No statistically significant difference was observed in inhalable dust levels during waste sorting, shredding, turning and screening. Despite this, final product screening and manual sorting of waste were

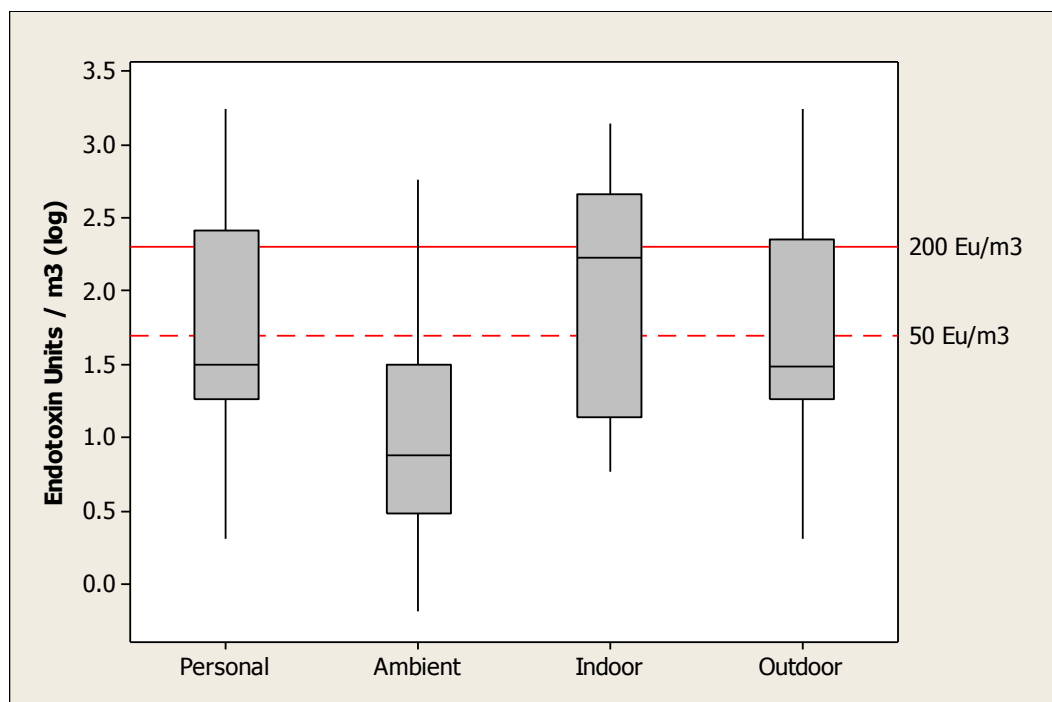
identified as areas of concern as high dust concentrations were experienced on occasion and further work is needed to investigate employee exposures whilst undertaking these activities.

#### 4.2. Endotoxin

Despite the relatively low dust levels, determination of the biological component of the dust indicated that employees' exposure to endotoxin was elevated (median 31.5 EU/m<sup>3</sup>, min 2.00 EU/m<sup>3</sup>, max 1741.78 EU/m<sup>3</sup>), particularly when waste was agitated during sorting, shredding and screening operations (median 178.1 EU/m<sup>3</sup>, min 6.02 EU/m<sup>3</sup>, max 1741.78 EU/m<sup>3</sup>).

The static sampling results showed large variations in endotoxin concentrations, range 0.65 to 584.02 EU/m<sup>3</sup>. Personal exposure levels for endotoxin were found to be higher than those obtained from static sampling, range 2.03 to 1741.78 EU/m<sup>3</sup>. Personal endotoxin levels were higher when operatives were working indoors, particularly when the waste is agitated.

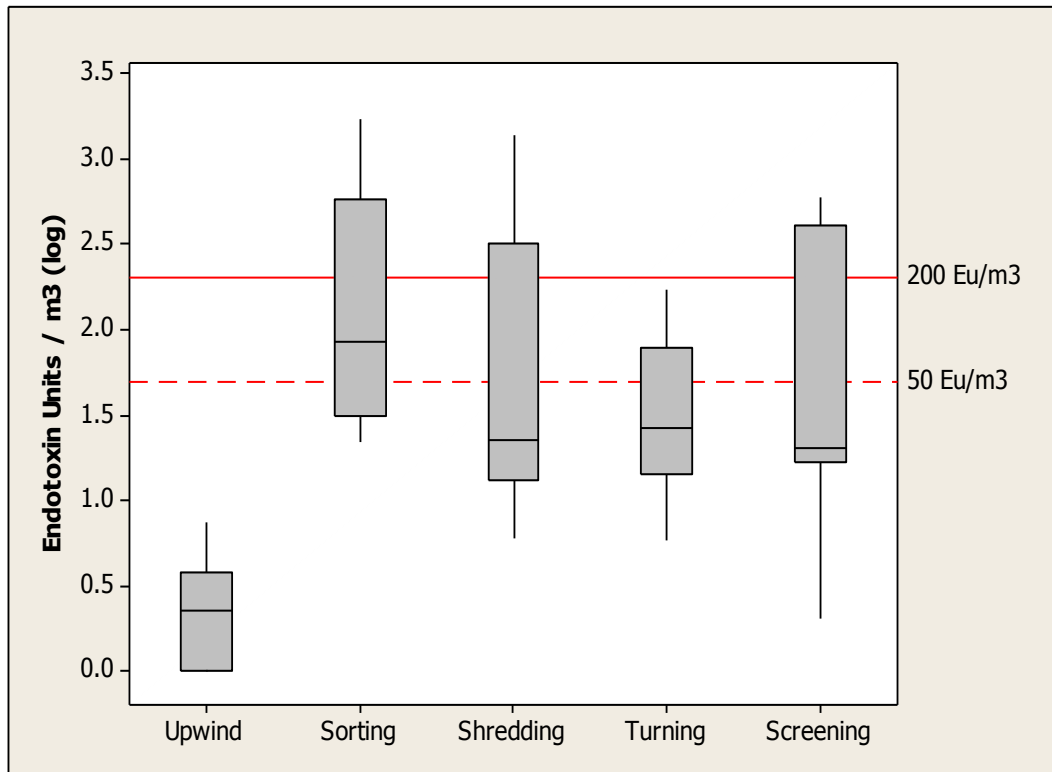
Figure 1 illustrates that, although not statistically significant, differences in employee exposures were seen in employees working indoors compared to outdoors and between personal sampling and static sampling results



**Figure 1.** Median and Inter-quartile range (log scale) of endotoxin exposure concentrations by location.

As shown in Figure 2, operational practices such as waste sorting, shredding, turning and screening was seen to increase bioaerosol liberation and had an increased effect on employee exposure to endotoxin. Eight out of 32 (25%) of the personal exposure data exceeding the 200 EU/m<sup>3</sup> temporary legal limit

adopted in the Netherlands and thirteen out of 32 (40.6%) exceed the 50 EU/m<sup>3</sup> guidance level suggested to protect workers from respiratory health effects [36].



**Figure 2.** Median and Interquartile range (log scale) of personal endotoxin exposure concentrations by predominant work activity.

#### 4.3. Glucan

Generally, employees' exposure to 1-3  $\beta$  Glucan was low (median 0.52 ng/m<sup>3</sup>, min 0.00 ng/m<sup>3</sup>, max 28.72 ng/m<sup>3</sup>). Five out of 32 (15.6%) exceeded the 10ng/m<sup>3</sup> level believed to be related to clinical symptoms [35].

There was a statistically significant correlation between employees' exposure to inhalable dust and personal endotoxin concentration (Spearman rho correlation coefficient  $r = 0.728$ ,  $p < 0.05$ ) and also between personal endotoxin exposure and 1-3  $\beta$  Glucan concentration (Spearman rho correlation coefficient  $r = 0.817$ ,  $p < 0.05$ ).

#### 5. Discussion

The findings of this study are consistent with others in that employees of composting sites are exposed to high levels of bacterial endotoxin [20,23,24] even though in most cases, their personal dust exposure is below regulatory levels.

The results obtained from this study are highly variable due to a number of influencing factors such as site operations and practices, waste composition and meteorological conditions. This has been highlighted in previous studies [30] and consequently the determination of ‘typical exposures’ from composing operations such as sorting, shredding, turning and screening is problematical.

The results indicate that employees’ exposure to dust and endotoxin was higher at indoor composting facilities. This finding requires further investigation and employees’ exposures to dust and endotoxin needs to be extensively characterised as indoor facilities are becoming more prevalent within the waste management industry.

The agitation of waste during various site activities resulted in generally higher employee exposures to dust and endotoxin. This increase however was not found to be statistically significant. Waste shredding, turning and screening is fundamental to the composting process and consequently practical risk mitigation measures are required to reduce employees’ exposure as far as reasonable practicable during these activities. The efficacy of any control measures adopted should be investigated to determine their actual impact on reducing employee exposure to dust and endotoxin.

There is general agreement that organic dusts containing bacterial endotoxin are associated with important adverse health effects and that this potential risk should not be considered as a general dust [35]. It is well established that endotoxin concentration is highly dependant on the process generating the dust and considerable variation in the levels of endotoxin concentrations have been described in a number of different industrial sectors such as composting, swine farming, grain handling and agriculture [40]. Consequently the general dust levels stipulated in the Control of Substances Hazardous to Health Regulations 2002 (as amended), as currently applied, are inadequate in effectively managing the potential risks specifically arising from the inhalation of endotoxin.

At present, endotoxin monitoring and analysis is unlikely to be widely adopted in the waste management industry due to cost and technical constraints in conducting the assay [3,25]. Consequently, if an occupational exposure standard for endotoxin was developed, it would be difficult to comply with in practice. This study does however indicate a significant correlation between inhalable dust and endotoxin concentration. Further work is needed to explore this relationship in order to establish whether dust may be used as a reliable proxy measure for endotoxin exposure. This may form the basis of a pragmatic, yet evidence-based way to regulate and manage employees’ exposure to endotoxin.

The potential risks from exposure to endotoxin at composting sites should be managed with caution at this present time. Site operators need to comprehensively assess the risk to site operatives from exposure to bioaerosols and implement personal monitoring, health surveillance, screening and immunological testing, where applicable, to manage these potential risks in a proactive and responsible manner.

## 6. Conclusion

Compost workers are exposed to airborne concentrations that may, in conjunction with other factors contribute to the development of respiratory symptoms. This study demonstrates that employees on composting sites are commonly exposed to levels of bacterial endotoxin believed to be associated with respiratory illness. Employee exposure to 1-3  $\beta$  Glucan was generally below levels considered to be related to adverse effects. There is however considerable uncertainty regarding the body burdens experienced by site operatives and the extent of dose-related effects from bioaerosol exposure at composting sites.

Employee exposure to endotoxin at composting sites is generally high, especially during operations that involve the agitation of waste. A significant correlation was found between the inhalable dust fraction and endotoxin concentration and further work is needed to explore the possibility of using inhalable dust concentration as a predictor for personal endotoxin concentration. The general dust levels that define a



dust as a ‘substance hazardous to health’ as stipulated in the Control of Substances Hazardous to Health Regulations 2002 (as amended) are inadequate for managing the potential health risks associated with endotoxin exposure at composting sites. At present, no statutory or reference levels exist in the UK for occupational exposure to endotoxin.

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