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PROGRESS TOWARDS A BEST PRACTICE METHOD FOR MODELLING DISPERSION OF BIOAEROSOLS FROM COMPOSTING FACILITIES

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SUMMARY: The promotion of composting in the UK as a sustainable waste management option has led to concerns regarding exposure of the public to potentially harmful emissions of airborne micro-organisms or bioaerosols. In response to public concerns, the Environment Agency in England and Wales requires a risk assessment for any licensed composting facility that has a sensitive receptor within 250m of the site boundary. An ongoing programme of studies in association with the Environment Agency has begun to explore methods to improve exposure assessments for bioaerosols. Our results have shown that is is possible to use air dispersion models for estimating downwind concentrations of bioaerosols, and the more advanced modelling options, such as the use of intermittent emission rates, result in lower downwind concentrations. Current risk assessments may be over-estimating the exposure of receptors to bioaerosols from composting, however further studies are needed to validate the results presented here.

1. INTRODUCTION

The promotion of composting in the UK as a more sustainable waste management option has led to concerns regarding exposure of the public to potentially harmful emissions of airborne micro-organisms or bioaerosols. The composting process is reliant on various micro-organisms, such as bacteria and fungi, to break down the organic matter. However, if as a result of composting operations these micro-organisms become airborne, may be breathed in, and due to their small size, can penetrate deep into the human respiratory system. Conditions such as farmer's lung disease and aspergillosis (Latgé, 1999) have been linked to high concentrations of bioaerosols, although dose-response relationships are not well defined.

In response to public concerns, the Environment Agency in England and Wales requires a risk assessment for any licensed composting facility that has a sensitive receptor within 250m of the

site boundary. In this context, sensitive receptors may include people within nearby residences, schools or office buildings. The aim of the risk assessment is to provide a useful tool for risk management. However, the quality of the risk assessment is dependant on the availability and quality of the bioaerosol source term data employed (Pollard S.J.T., Smith R., & al 2006). These data are frequently limited, in part because of the practical difficulties of microbiological analyses, but also due to cost constraints.

In response to these difficulties, an ongoing programme of studies in association with the Environment Agency is exploring methods to improve exposure assessments for bioaerosols. The objectives are:

- To improve the quality of bioaerosol source term data
- To examine the impact of bioaerosol properties on modelled downwind concentrations
- To examine the impact of the timing of on-site activities on bioaerosol emissions and dispersion

The collection of source term data is needed to overcome the difficulties of source apportionment. Bioaerosols are ubiquitous, so determining the exact source of emissions can be difficult. Sampling downwind of a source may therefore result in contamination from other nearby sources, such as livestock sheds, and the incorrect estimation of the contribution of each source to the sampled concentration. The use of dispersion models can, in theory, overcome this difficulty, as they require source term data as an input, and then predict the downwind concentrations, independent of other sources.

In our studies, two different air dispersion models have been used. The SCREEN3 air dispersion model (USEPA, 1995) is a 'screening-level' model designed for initial analysis of new pollution sources. The model uses steady-state Gaussian plume algorithms and meteorological scenarios to estimate worst-case concentrations downwind of a single source. The ADMS 3.3 air dispersion model (Carruthers D.J., Holroyd R.J. & al, 1994; CERC, 2003) is an advanced steady state, Gaussian-like dispersion model. The model can simulate emissions from a number of different sources and can examine the impact at a number of user-defined receptors. This more advanced model was used to examine the influence of a number of variables on bioaerosol dispersal. These include the combined emissions from several sources, the usefulness of observed meteorological data and the input of emissions that vary over time.

Our initial studies (Taha M.P.M., Pollard S.J.T. & al, 2005) showed that it was possible to capture bioaerosol emissions from static compost windrows using the wind tunnel approach and to calculate source term emission rates that could be used in a dispersion model (SCREEN3). In a follow-up study (Taha M.P.M., Drew G.H. & al, 2006), we were able to model downwind dispersion of bioaerosols from agitation activities. These studies were based on several simplifiying and limiting assumptions:

- The particles displayed a Gaussian distribution in both lateral (crosswind) and vertical directions;
- No gravitation deposition was assumed;
- Only one source was modelled;
- The source was assumed to be continuous;
- The wind velocity and direction were assumed to be constant over modelled time and distance;
- The modelled surface was relatively flat;
- The particle and wind velocity were assumed to be the same; and
- Microbial inactivation and aggregation were not considered.

In order to examine the influences of these assumptions, the ADMS 3.3 model was used, as the more advanced options within the model permit the examination of these variables. It was

therefore necessary to compare the output from the two models. This comparison (Taha M.P.M., Drew G.H. & al, 2007) showed that the SCREEN3 model estimates of downwind concentrations are always higher than the ADMS 3.3 predictions. This is expected, as the SCREEN3 model is designed to predict the worst case scenario. In addition, the ADMS 3.3 model was used to predict the combined emissions from more than one source. This is a more realistic representation of dispersion from the facility, as composting facilities tend to have several sources of bioaerosols, including static compost windrows and agitation activities, such as shredding, screening and turning of the compost. This study showed that modelling the combined active and passive sources together resulted in predictions that were closer to background concentrations in comparison to modelling the passive sources alone. This suggests that the major contribution to bioaerosol emissions from composting facilities is from agitation activities, i.e. active sources, which by their nature are episodic.

We then examined the impact of meteorological data and modelling bioaerosols as particles (Drew G.H., Tamer A., & al, 2006). The results from this study showed that the use of hourly observed meteorological data results in lower downwind bioaerosol concentrations than the use of the Pasquill stability classes, which define seven standard atmospheric conditions. Modelling bioaerosols as particles, as opposed to a gas, resulted in a further lowering of predicted downwind conentrations.

The next stage in the process of examining the influence of our initial simplifying assumptions was to compare the difference between downwind concentrations based on a continuous source and those based on intermittent emissions. This was achieved by taking into account the number of hours during a typical week when the compost is being agitated and when no activity occurs on site, as well as the change in bioaerosol emissions from compost of different ages.

2. METHODOLOGY

2.1 Source term data collection

Our initial studies focused on collecting authentic source term data. This was achieved using a wind tunnel and personal aerosol samplers to collect bioaerosol emissions from static compost windrows and two in-vessel composting facilities. In addition, bioaerosol samples were taken as close as practically possible to compost agitation activies, such as turning, screening and shredding. The proximity of sampling to the activities was determined with consideration for the safety of the sampling team.

The sampling sites represent a variety of different processes and treat several different types of material. This includes three green waste open windrow facilities, one animal by-products in-vessel composting facility and one municipal solid waste in-vessel composting facility. For this study, samples were collected over a period of three months from green waste compost windrows at different stages in the composting process. Various composting agitation activities were also sampled and the site managers provided information on the typical number of hours per week that each activity occurs during the summer and winter months. Samples were also taken 30m downwind of the facility.

Bioaerosol sampling was carried out using a personal air filter sampler (SKC pump fitted with IOM sampler heads), which draws a known volume of air through a filter medium (0.8 μm polycarbonate) where bioaerosols are captured. Two pumps were used to take two simultaneous samples from each sampling point. The average results from the two samples taken at each sampling point were used for analysis and dispersion modelling. All equipment was sterilised before being taken onto site. A Kestrel 3000 pocket size anemometer (Meterologica Ltd.,

Lancashire) was used to determine the wind direction, temperature, relative humidity and wind speed. General weather conditions, such as rain or strong winds were noted.

Collected microorganisms were quantified using the plate count analysis steps of the CAMNEA-method (Palmgren U., Strom G. & al, 1986) followed by visual enumeration. Actinomycetes species were incubated for 7 days at 44ºC and *Aspergillus fumigatus* for 3-5 days at 37ºC. The results were expressed using the equations from British Standard 5763 Part 0: General laboratory practices. Further details on the bioaerosol source term data and enumeration methodologies from these sites are presented in Taha M.P.M., Pollard S.J.T. & al (2005), Taha M.P.M., Drew G.H. & al (2006; 2007), and Tamer Vestlund A., Drew G.H. & al (2007).

2.2 Dispersion modelling

When modelling the emissions, the static compost windrows are usually treated as area sources, while the agitation activities are modelled as point sources. However, when modelling intermittent sources, ADMS 3.3 requires that all sources be represented as point sources. The compost windrow was therefore represented as 4 point sources, each with a diameter of 20m, so that together they represent the area covered by the windrow. In addition, 3 agitation activities, namely shredding, turning and screening were modelled as point sources.

The model was run for three months over the summer, and three months over the winter, with hourly meteorological data, and with the Pasquill stability classes. The model was set to produce long term average concentrations as output. Initially, the emissions from each source were input as a constant value for each of the 2 seasons. The model was then run with the emissions varying during the week (Table 1) and as the compost aged (Table 2), based on the data collected by Taha M.P.M., Drew G.H. & al (2007).

Table 1: Details of the intermittent emission rates for the agitation activities (point sources).

Parameter	Shredding	Turning	Screening
A. fumigatus (cfu/s)	17 850	95 500	17 750
Actinomycetes (cfu/s)	7 900	262 500	13 500
Hours occurring in summer	7	3	9
Hours occurring in winter	2	1	3

Table 2: Emission rates for the compost windrow (areas source) as the compost aged.

Age (weeks)	*A. fumigatus* (cfu/s)	Actinomycetes (cfu/s)
0-2	0	220 000
3-4	120 000	80 000
5-6	80 000	340 000
7-8	120 000	100 000
9-12	160 000	360 000
13-16	80 000	200 000

3. RESULTS AND DISCUSSION

The results from the intermittent emissions experiments are presented in Figure 1 (winter) and Figure 2 (summer). These results show that where intermittent emissions have been used, the predicted downwind concentrations are lower than when all the emissions are constant. This result suggests that current methods of estimating receptor exposure to downwind bioaerosol concentrations, based on constant emissions, are over-estimating the exposure. The downwind concentrations (shown as blue triangle for *Aspergillus fumigatus* and a red star for actinomycetes) are also considerably higher than the modelled downwind concentrations. As the modelled concentrations are based entirely on emissions captured on-site, it is possible that the measured downwind concentrations were influenced by the existence of other sources of bioaerosols. However, as it is currently not possible to distinguish between bioaerosols captured from difference sources (source apportionment), we cannot validate this assumption. These results do suggest opportunities for future studies. Firstly, a detailed study of the emissions from different bioaerosol sources downwind of a composting facility would provide some indication of the relative contributions of those sources to the ambient bioaerosol concentrations. Secondly, detailed monitoring of bioaerosol concentrations at receptors could indicate their true level of exposure, based on the modelled results presented here, which suggest that exposure is over-estimated using current methods.

In addition to the intermittent emissions results, Figure 3 shows the influence of meteorological data on downwind concentrations of bioaerosols, as predicted by the dispersion model. The experiments shown on this graph all use the identical emission rates for each of the two micro-organisms. For the summer, the temperature of the emission is set at a constant of 30ºC, while the winter temperature was set at 15ºC. The Pasquill experiments use the Pasquill stability classes, while the other experiments use 3 months of hourly meteorological data. If one examines only the Pasquill experiments, the colder temperature set for winter results in higher downwind bioaerosol concentrations than the warmer temperature in the summer experiment. The winter source depletion curve is also smoother than the summer depletion curve, particularly at distances close to the source, suggesting that the colder temperatures result in a more constant drop out from the plume, with more variation when temperatures are higher. However, the results from the hourly meteorological data show that the modelled downwind concentrations for the winter are lower than the summer modelled concentrations.

A comparison between the results from the hourly meteorological data and the Pasquill stability class experiments shows that the use of the hourly meteorological data results in lower downwind concentrations than the use of the Pasquill stability classes. Results from a previous study (Drew G.H., Tamer A., & al, 2006) showed the same trend. The most marked difference in these modelled results is shown up to 200m downwind of the source. The slope of the curves based on the hourly meteorological data is greater than those based on the Pasquill stability classes. For the Pasquill stability class runs, the average wind speed is 2.7 m/s, but for the hourly meteorological data, the average wind speed is 5.4 m/s for the summer and 6.5 m/s for the winter. The greater turbulence caused by the increased wind speeds from the observed meteorological data results in greater dilution of the plume and decreases downwind concentrations.

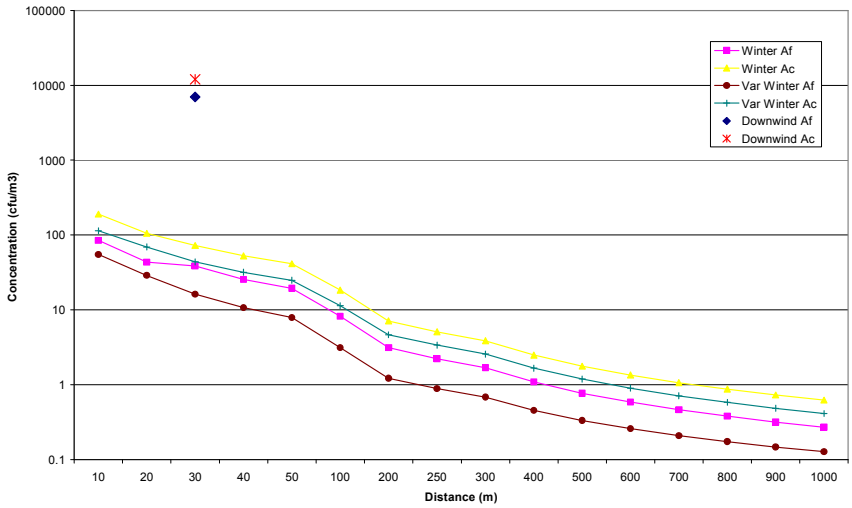


Figure 1. Modelled predicted concentrations of *A. fumigatus* (Af) and actinomycetes (Ac) for the winter, showing both constant emissions and intermittent emissions.

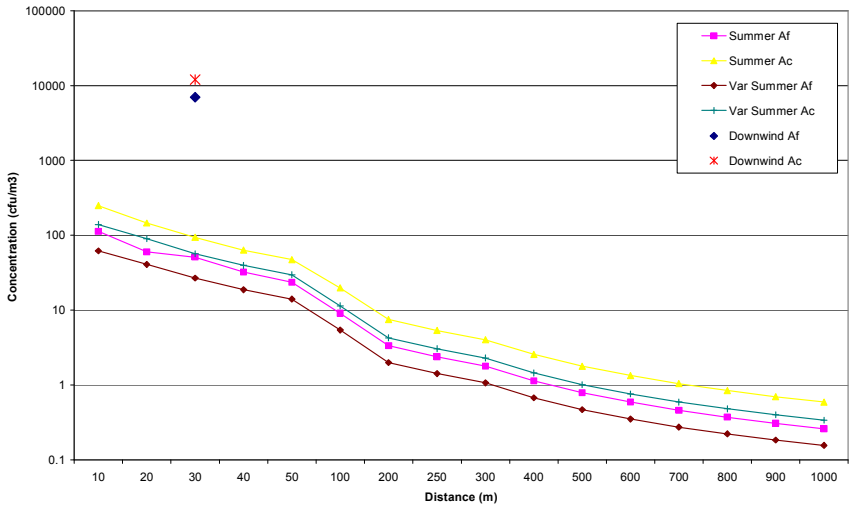


Figure 2. Modelled predicted concentrations of *A. fumigatus* (Af) and actinomycetes (Ac) for the summer, showing both constant emissions and intermittent emissions.

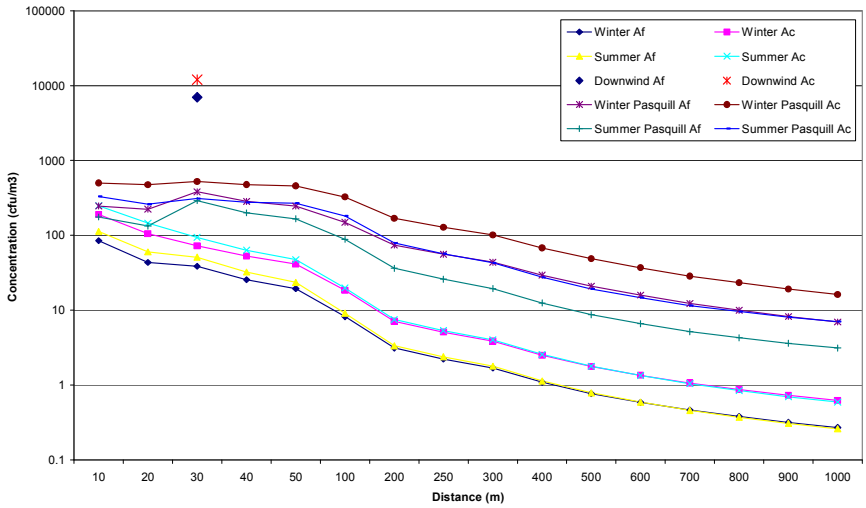


Figure 3. The influence of season and meterological data on modelled predicted concentrations of *A. fumigatus* (Af) and actinomycetes (Ac).

5. CONCLUSIONS

Our results to date have shown that it is possible to capture and model bioaerosol emissions from composting facilities, using air dispersion models developed for more traditional pollutants, such as odours. We have also shown that the more advanced modelling options, such as modelling bioaerosols as particles and the use of hourly observed meteorological data, results in lower downwind bioaerosol concentrations than when these factors are not considered. The results presented here have added further weight to these conclusions, and warmer temperatures were shown to result in higher downwind concentrations than colder temperatures, as evidenced by the advanced dispersion model.

In addition, we have examined the influence of intermittent emissions on downwind modelled bioaerosol concentrations. The use of intermittent emissions in modelling bioaerosol concentrations results in lower downwind concentrations of bioaerosols in comparison to sources with constant emissions. This result suggests that current methods over-estimate downwind receptor exposure to bioaerosols.

The results presented here provide us with more questions than answers. In particular, how do we validate the model results? Sampling downwind of a facility may capture emissions from that facility, but these sampled concentrations may also be contaminated by other sources of bioaerosols, due to their ubiquitous nature. We therefore need to find a method to determine the true emissions from different sources downwind of composting facilities, in order to estimate the contribution of each source to the ambient bioaerosol concentration.

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