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Effect of *Thiobacillus thioparus* 1904 and sulphur addition on odour emission during aerobic composting

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A R T I C L E I N F O

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A B S T R A C T

The effects of sulphur and *Thiobacillus thioparus* 1904 on odour emissions during composting were studied. Results indicated that the sulphur addition reduced the pH and decreased cumulative emission of ammonia and the nitrogen loss by 47.80% and 44.23%, respectively, but the amount of volatile sulphur compounds (VSCs) and the sulphur loss increased. The addition of *T. thioparus* 1904 effectively reduced the cumulative emissions of H_2S, methyl sulphide, methanethiol, dimethyl disulphide and the sulphur loss by 33.24%, 81.24%, 32.70%, 54.22% and 54.24%, respectively. *T. thioparus* 1904 also limited the nitrogen loss. The combined application of sulphur and *T. thioparus* 1904 resulted in the greatest amount of nitrogen retention. The accumulation of ammonia emissions was reduced by 63.33%, and the nitrogen loss was reduced by 71.93%. The combined treatment did not increase the emission of VSCs. The application of sulphur and *T. thioparus* 1904 may help to control the odour of compost.

1. Introduction

The global annual production of livestock and poultry manure, crop stalks and other agricultural solid organic waste is highly substantial. Aerobic composting has become the main method to treat these solid wastes to harmlessly reduce their concentrations and improve resource utilisation (Maeda et al., 2010; Maeda et al., 2011; Zeng et al., 2012). However, the nitrogen loss and emission of odours seriously affects the quality of the compost (Zhang et al., 2016b; Tsai et al., 2008). The odour problem has become a major issue in the development of aerobic composting (Pagans et al., 2005; Domingo and Nadal, 2009; Schlegelmilch et al., 2005).

The main components of odour from compost are NH_3, H_2S and VSCs·NH_3 is produced by the organic decomposition of nitrogen-containing compounds in the compost, and the nitrogen loss during the composting process is mainly due to the emission of ammonia. Therefore, the conservation of nitrogen in the compost and deodourisation are inseparable. H_2S and VSCs are produced from the decomposition of sulphur-containing organic matter when the compost is in micro-aerobic or anaerobic conditions. There are two solutions for treating the emission of odours: *in situ* emission reduction and ectopic treatment. To achieve both deodourisation and nitrogen protection, *in situ* emission reduction is necessary. The main methods of *in situ* emission reduction include two major categories. One is to change the composting conditions, such as introducing appropriate ventilation, humidity and temperature (Iannotti et al., 1994; Zhang et al., 2016b); the second is to utilise compost additives that could reduce the pH and the loss of nitrogen (Zhang et al., 2016b; Kithome et al., 1999; Kuroda et al., 2004; Lin et al., 2008; Mahimairaja et al., 1994; Zang et al., 2017).

Sulphur is an acidic chemical that can effectively reduce the pH of the compost. It increases the content of sulphur in the compost and provides indispensable sulphur elements for the process of plant growth. Roig et al. (2004) added sulphur to olive oil plant waste to control the pH of the compost. Garcı'a de la Fuente et al. (2007) applied sulphur in different organic composts to reduce their pH values. The results from Bustamante et al. (2016) showed that the addition of sulphur could not only reduce the compost pH but also increase the available content of phosphorus. Since plants have difficulty absorbing elemental sulphur, this compound has bactericidal and bacteriostatic effects. The addition of sulphur alone affects the temperature of composting, but adding *T. thioparus* and sulphur together relieves this inhibition, enabling the compost temperature to increase normally and maintain a long period of high temperatures. (Wenjie et al., 2011). *T. thioparus* has been identified as a bacterium capable of oxidising both organic and inorganic sulphur compounds.

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Although studies have shown that sulphur can control the compost pH, its effect on the emission of ammonia from the compost has been studied less frequently. Whether the addition of sulphur will reduce the emission of ammonia and cause an increase in the VSCs is also unknown. *T. thioparus* has been used to control odour in biofilter treatments but is rare in aerobic composting. The effect of the addition of *T. thioparus* on the control of VSCs in compost is also unclear. These factors represent the core contents of this study. The purpose of this study is to further clarify the effect of sulphur and *T. thioparus* addition on the emission of odour from compost that has been the basis of previous studies and provide a theoretical basis for the combination of sulphur and *T. thioparus*.

2. Materials and methods

2.1. Inoculant of composting

The laboratory-preserved strain *Thiobacillus thioparus* 1904 was inoculated in a liquid fermentation medium at 30 °C, 180 r min^{-1} and cultured for three days. Then, the activated *T. thioparus* 1904 was inoculated into a small liquid fermenter (Shanghai Jiaotong University, SY3000E) utilising 5% of inoculum, and the fermentation broth was left to react for five days. The fermentation medium was Na_2HPO_4 1.2 g, KH_2PO_4 1.8 g, $MgSO_4{\cdot}7H_2O$ 0.1 g, $(NH_4)_2SO_4$ 0.1 g, $CaCl_2$ 0.03 g, $FeCl_3$ 0.02 g, $MnSO_4$ 0.02 g, $Na_2S_2O_3$ 10.0 g, distilled water 1.0 L, autoclaved at 121 °C for 15 min. The overflow *T. thioparus* 1904 was centrifuged, and the supernatant was removed and suspended in sterile water to a concentration of 1×10^8 CFU ml^{-1}.

2.2. Composting materials and methods

Mushroom residues and chicken manure were used as the materials for the static aerobic composting and were obtained from edible Guangdong Dongguan Xinghe Biotech Company Fungus Factory and Zhongluotan Town poultry farm in Guangzhou City, Baiyun District, respectively. Selected characteristics of the materials are shown in Table 1. Mushroom residues and chicken manure were mixed at a 1:1 (w:w) ratio, and the moisture was adjusted to approximately 50%. Sulphur in the form of an industrial powder was bought from a market. A pilot-scale compost system was used that was modified from a reactor. The compost reactors consisted of stainless steel cylinders with 100 L effective volumes (Fig. 1). There was a temperature probe inside the reactor to monitor the temperature, and ventilation devices were installed at the same time that could be automatically controlled to ventilate the dry matter at 0.2 L kg min^{-1} with a ventilation frequency of 10 min intervals for 6 h. The static aerobic compost lasted for 21 days.

2.3. Experimental design

There were four treatments utilised in this study: (1) raw material (T1), (2) raw material + 0.25% sulphur (material dry weight) (T2), (3) raw material + 0.25% sulphur + *T. thioparus* 1904 inoculum (T3), (4) raw material + *T. thioparus* 1904 inoculum (T4). The amount of *T. thioparus* 1904 inoculum added was 5% (v:w). The sulphur and *T. thioparus* 1904 inoculum were sprayed during the mixing process. Samples were collected at the initial day, 3rd day, 5th day, 7th day, 10th day, 14th day and 21th day for a total of seven times. The sampling point was 35–45 cm below the surface of the reactor that was mixed thoroughly for analysis. The amount sampled each time was approximately 500 g from the centre and the four corners. Fresh samples were collected to determine the pH, ammonia nitrogen and nitrate nitrogen. Part of the samples was dried and crushed through a 1 mm sieve to obtain the total nitrogen and available sulphur and to determine the total sulphur. The rest of the samples were stored in a refrigerator at 4 °C. The fan on the top of the reactor was opened 15 min before the gas was sampled, so that the gas in the reactor would be completely mixed. One-litre samples of gas were collected each time.

2.4. Experiments methods

The compost temperature was tested utilising a PT-100 platinum electrode every 6 h. A fresh subsample was extracted with distilled water or 1.0 M KCl at a ratio of 1:10 (w:v) for 1 h and then centrifuged. After centrifugation, the water-based supernatant was used to measure the pH (PB-10 Sartorius). The KCl-based supernatant was analysed for ammonium N and nitrate N using a flow injection analyser (AMS FRANCE FUTURA). The total N was determined by the Kjeldahl method. The samples were air-dried and digested with H_2SO_4-H_2O_2. The total S concentration was determined by acid oxidation with HNO_3, $HClO_4$, H_3PO_4 and HCl (Page et al., 1982) followed by turbidimetry at a wavelength of 440 nm to determine the sulphate concentrations in the digests. The available S was extracted by shaking a 1.0 g sample with 50 ml of a $Ca(H_2PO_4)_2$-HOAc solution for 1 h and then filtering it through a slow filter paper (Ghani et al., 1991). Twenty-five millilitres of filtrate was placed in a filter flask and boiled on an electric heating board while adding 30% H_2O_2 oxidised organic matter. After the complete decomposition of the organic matter, the residual H_2O_2 was eliminated by boiling. The sulphate in the solution was determined by turbidimetry after adding 1 ml of 1:4 HCl.

The determination (Zhang et al., 2013; Zhang et al., 2016b) of NH_3 gas involved trapping with boric acid (2%) followed by titration against 0.5 M H_2SO_4. H_2S, methyl sulphide, dimethyl disulphide, and methanethiol were determined by gas chromatography (GB/T14678-1933 as a reference). The sulphide in the 1 L gas sample was concentrated under low temperature conditions with liquid nitrogen as the coolant. The concentrated gas was analysed by gas chromatography (Agilent 7890A, Agilent Technologies, USA) utilising an electron capture detector. The various sulphide components were quantified utilising an FPD detector, and N_2O was analysed quantitatively with electronic catchers (Ruirui et al., 2015).

2.5. Data analysis

The mean and standard deviation of three replicates were reported. One way analysis of variance (ANOVA) was performed to compare the composting treatments, while multiple comparisons between every two treatments were performed using the Least Significant Difference test (LSD-t). SPSS for Windows, release 16.0, was used to perform all the statistical analyses.

3. Results and discussion

3.1. Temperature

Temperature is an important parameter to use to monitor the composting process. Fig. 2 shows that the temperature trends of the

Table 1
Physical-chemical properties of the composting materials.

Raw material	Moisture content (%)	C/N ratio	Organic matter (%)	Total N (%)	Total P (%)	Total K (%)
Chicken manure	34.76 ± 1.19	7.10	48.58 ± 2.05	3.97 ± 0.04	2.81 ± 0.14	4.04 ± 0.20
Mushroom residue	10.76 ± 0.27	30.17	82.28 ± 1.60	1.62 ± 0.08	1.87 ± 0.13	1.18 ± 0.10