



## Ammonia emissions and biodegradation of organic carbon during sewage sludge composting with different extra carbon sources



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### ABSTRACT

Ammonia emissions during composting result in the reduced value of agronomic production and can also pollute the air. To evaluate the influence of various carbon sources on ammonia emissions, six composting experiments were carried out with different amendments of carbon sources (glucose, sucrose and straw powder). The cumulative ammonia volatilizations were reduced from 3.11 g/kg (R6) to 2.46 g/kg (R1), 2.17 g/kg (R2), 2.23 g/kg (R4) and 1.93 g/kg (R5). Compared to the control, no significant difference of ammonia emissions and carbon degradation was observed for the mixture of R3 (3.15 g/kg), which was amended with straw powder alone. The co-addition of sucrose and straw powder led to the lowest ammonia emissions. According to these results, a higher C/N ratio did not necessarily indicate an effective solution for reducing ammonia emissions, and not all readily available carbon compounds were helpful in reducing ammonia emissions. The addition of sucrose promoted the decomposition of organic carbon during the intensive stage of ammonia emissions, and the combination of straw and sucrose prolonged this promotion. Thus, the co-addition of sucrose and straw powder made it possible to reduce ammonia emissions drastically by nitrogen immobilization.

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### 1. Introduction

Sewage sludge is an inevitable by-product of the wastewater treatment process. Recently, the production of sewage sludge increased rapidly with the improvement of municipal wastewater treatment capacity in China (Wang, 1997). Composting is one of the most widely employed approaches for disposing of sewage sludge because of its cost reduction, easy application and low pollution (Wang et al., 2011). During the aerobic thermophilic composting process, complex and unstable organic constituents convert into a relatively stable humus-like material, which can be handled, stored, and used as a soil conditioner and fertilizer (Haug, 1993).

Nitrogen is easily lost through ammonia volatilization, which reduces the fertilizing ability of the manure and causes environmental odor pollution problems (Ogunwande et al., 2008). It is well known that an excess amount of nitrogen is released when the initial C/N ratio is small (Jiang et al., 2011); therefore, to reduce

ammonia emissions, several researchers have sought to increase the C/N ratio by using carbon amendments. Various carbon-rich compounds such as sawdust, straw and paper have been used as carbon amendments in several studies (Kirchmann and Witter, 1989; Nakasaki et al., 2001; Torkashvand, 2009). However, when different materials have been added, their effectiveness in reducing ammonia emissions has not been evident. For example, Mahimairaja et al. (1994) demonstrated that ammonia loss was reduced by 33% in manure amended with wheat straw. Increasing the straw additions to manure reduced ammonia volatilization during aerobic composting from 44% to 9% (Kirchmann and Witter, 1989). In contrast, Gilhespy et al. (2009) indicated that the increasing the concentration of straw amendments increased the temperature of the composting pile and hence promoted ammonia emissions. A few studies have reported that molasses, a readily available carbon, appeared to effectively reduce ammonia emissions (Subair, 1995; Liang et al., 2006; Torkashvand, 2009). Furthermore, because of its high C/N ratio, sawdust was also popularly used to regulate such ratios in composts. However, Subair (1995) found that the effectiveness of sawdust on reducing ammonia emissions may not be due to nitrogen bio-immobilization but to physical adsorption.

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It is difficult to evaluate the direct effects of the C/N ratio on ammonia emissions. Therefore, this factor is not a suitable and exclusive indicator for reducing nitrogen loss. Other factors, such as the types of carbon sources, chemical form and the particle size of the carbon source may also influence ammonia emissions. Despite the fact that several researchers have observed significant effects of carbon-rich compounds on nitrogen loss, there is little information available in literature regarding the interaction between carbon degradation rates and ammonia emissions using different carbon amendments (Matsumura et al., 2010). It is difficult to explain why different types of carbon sources show different effects on reducing ammonia emissions; thus, it is necessary to examine factors other than the C/N ratio that can affect ammonia emissions.

Thus, in our study, different carbon-rich amendments with different degradation rates, such as glucose, sucrose, straw powder and mixtures of straw powder and glucose or sucrose were added at the beginning of composting. The objectives of the current study are 1) to assess the effects of these carbon compounds on composting performance and ammonia emissions during sewage sludge composting and 2) to discuss the interaction between degradation rate of carbon compounds and ammonia emissions.

## 2. Materials and methods

### 2.1. Composting materials and experimental design

Dewatered sewage sludge (SS) was collected from the Wenchang (China) urban sewage treatment plant. Because of the excessive humidity of SS, sawdust was used as a bulking agent to regulate moisture content and provide optimum free air space. Before mixing with the SS, the sawdust, which was considered an inner material, was manually cut to a width of 2.5 mm and a length of 16 mm. The soluble organic matter from the sawdust could be ignored because of its insignificant effects compared to SS or other carbon-rich amendments.

To obtain reproducible data, the same composting material was used throughout the experiment. Approximately 1460 g of SS and 280 g of sawdust were well mixed and divided into six parts. Each part had the same composition (243.3 g SS and 46.6 g sawdust). Various carbon-rich amendments — glucose, sucrose, straw powder and mixtures of glucose or sucrose and straw powder — were added. Six laboratory-scale composting experiments with different amendments were set up as following: R1 (5 g glucose, 243.3 g SS and 46.6 g sawdust), R2 (5 g sucrose, 243.3 g SS and 46.6 g sawdust), R3 (5 g straw powder, 243.3 g SS and 46.6 g sawdust), R4 (5 g glucose, 5 g straw powder, 243.3 g SS and 46.6 g sawdust), R5 (5 g sucrose, 5 g straw powder, 243.3 g SS and 46.6 g sawdust), R6 (No amendment except for 243.3 g SS and 46.6 g sawdust). The characteristics of the raw materials are presented in Table 1.

The composting experiments were conducted in column reactors (100 mm in diameter, 300 mm in depth) made of glass. This reactor was equipped with a silicone rubber stopper at the top. Three holes were drilled into this silicone rubber stopper, the first one used for aeration, the second for detecting temperature, and the last one for collecting exhaust gas. The aeration rate was monitored by a flowmeter (LZB, China) and maintained at  $0.135 \text{ L h}^{-1}$ , which was considered sufficient for maintaining aerobic conditions based on our preliminary experiment. The exhaust gas from composting reactor passed through a 250 mL Erlenmeyer flask containing 50 mL 2% boric acid to capture the ammonia. To minimize heat loss and simulate a self-heating reactor, all of the composting reactors were placed in a water bath with a temperature sensor in it to measure the environmental temperature. The temperature of the water bath was maintained below that inside the reactor (approximately 3–5 °C). This temperature-controlling

**Table 1**

The characteristics of the raw composting materials.

Parameters	Moisture content (%)	pH	Kjeldahl N (%)	TOC (%)	C/N
Sewage Sludge	86.6 ± 0.6	6.9 ± 0.4	3.13 ± 0.12	23.1 ± 1.7	7.38
Sawdust	9.1 ± 0.05	7.1 ± 0.5	0.12 ± 0.004	48.8 ± 1.2	406.7
Straw powder	6.7 ± 0.03	7.2 ± 0.04	0.24 ± 0.005	44.3 ± 2.3	184.6
Glucose	nd	nd	nd	39.96	nd
Sucrose	nd	nd	nd	42.07	nd
R1	63.4 ± 1.5	5.45 ± 0.04	2.09 ± 0.04	26.8 ± 0.7	12.8
R2	62.6 ± 2.1	5.23 ± 0.17	2.06 ± 0.17	26.7 ± 1.12	12.9
R3	63.4 ± 1.8	7.52 ± 0.21	2.03 ± 0.21	26.2 ± 0.87	12.9
R4	61.8 ± 1.5	5.31 ± 0.23	2.02 ± 0.23	27.9 ± 0.54	13.8
R5	62.4 ± 1.5	6.14 ± 0.06	1.95 ± 0.06	27.6 ± 0.87	14.15
R6	62.1 ± 1.5	7.63 ± 0.04	2.10 ± 0.04	24.3 ± 0.97	11.5

nd, not detected; Each value is the mean of triplicates (dry weight basis).

procedure has been reported by Lashermes et al. (2012) and Mason and Milke (2005).

### 2.2. Chemical analysis

A thermometer was inserted into the composting pile to record the temperature every 24 h at the same point inside the reactor. Ammonia in the exhaust gas was trapped by a 2%  $\text{H}_3\text{BO}_4$  solution and measured by titration (Al-Kanani et al., 1992). The concentrations of ammonia were measured every 24 h until the temperature dropped below 40 °C. After the initial measurements, the exhaust gas was analyzed every 48 h due to a reduction in emissions, and the absorbent solution was replenished after each titration.

The solid composting samples were collected at specific intervals based on temperature evolution: day 0, the starting period; day 3, the thermophilic phase; day 6, the end of thermophilic phase; and day 22, the end of the composting process. To reduce the measurement error, all samples were taken from the center of the composter after stirring the composted material, and then mixed together to form a homogeneous sample material. Moisture content, pH and  $\text{NH}_4^+\text{-N}$  were determined by analyzing fresh composting samples. Total organic carbon, organic matter and Kjeldahl nitrogen were determined using samples after drying. Moisture content was measured by weight loss of the compost sample after drying at 105 °C for 24 h (Nakasaki et al., 1998). After measuring the moisture content, the organic matter or ash of the dried sample was determined by burning it at 550 °C for 4 h (Witter and Lopez-Real, 1988). The pH was determined using the pH meter (PH-S) by dissolving 1 g compost sample (<1 mm) in 10 mL distilled water (Rihani et al., 2010).  $\text{NH}_4^+\text{-N}$  was extracted with 50 mL 2 mol/L KCl (1 g solid sample with a 50 mL KCl solution) on a shaker at 150 rpm and environmental temperature for 1 h, measured by the Indophenol Blue method and followed by colorimetric (Li et al., 2012). The total organic carbon was determined following the standardized method of Walkley–Black wet combustion method (Walkley and Black, 1934). The Kjeldahl nitrogen of the composting sample was determined by using the Kjeldahl method (Bremner and Mulvaney, 1982).

All presented results were average values of triplicated measurements, and the maximum difference among the triplicate results was 5%. During composting, significant differences among the values of each studied parameter were calculated by the least significant difference (LSD) test at  $p < 0.05$  by SPSS 17.0.

## 3. Results and discussion

### 3.1. Temperature

Temperature is an important indicator both for both decomposition rates and microbial activity in composting (Woodford, 2009).

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