Influence of lime on struvite formation and nitrogen conservation during food waste composting

Xuan Wang, Ammaiyappan Selvam, Jonathan W.C. Wong *

Sino-Forest Applied Research Centre for Pearl River Delta Environment and Department of Biology, Hong Kong Baptist University, Hong Kong Special Administrative Region

HIGHLIGHTS

- Interaction between lime and struvite mediated nitrogen conservation was studied.
- N loss was reduced by 38% through struvite formation in presence of lime.
- 2.25% lime addition is effective in controlling acidity and struvite formation.
- Nitrogen fixed in struvite decreased when the lime dosage increased.

ARTICLE INFO

ABSTRACT

This study aimed at investigating the feasibility of supplementing lime with struvite salts to reduce ammonia emission and salinity consequently to accelerate the compost maturity. Composting was performed in 20-L bench-scale reactors for 35 days using artificial food waste mixed with sawdust at 1.2:1 (w/w dry basis), and Mg and P salts (MgO and K_2HPO_4, respectively). Nitrogen loss was significantly reduced from 44.3% to 27.4% during composting through struvite formation even with the addition of lime. Lime addition significantly reduced the salinity to less than 4 mS/cm with a positive effect on improving compost maturity. Thus addition of both lime and struvite salts synergistically provide advantages to buffer the pH, reduce ammonia emission and salinity, and accelerate food waste composting.

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1. Introduction

Food waste is the largest organic component of municipal solid waste by weight and constitutes about 14–40% in different countries (Levis et al., 2010). In Hong Kong, about 1.33 million tonnes of food wastes were disposed in landfills during 2014 (HKEPD, 2015). Landfill disposal of food wastes, as practiced or being practiced in many countries, not just reduces the life span of landfills, but also emits greenhouse gases and produces leachates requiring treatment. Hence, food wastes should be diverted from landfilling through appropriate treatment technologies. Composting, a biological process converting organic wastes into relatively stable humus-like compost, is a well-developed technology suitable for treating food wastes due to its robustness and easy in operation. Despite that, food waste possesses poor physical and chemical

structure posing challenges during composting. Modifying the physical structure through addition of suitable bulking agents was demonstrated in earlier studies convincingly (Chang and Chen, 2010; Wong et al., 2009). In contrast, rapid degradation of easily available organic matter during the early stages of composting poses a stiff challenge and initiates a sequence of events leading to intensive acidification and slow composting process. The generation of low molecular weight organic acids reduces composting pH and the acidic pH inhibits the microbiological activity and cause acidic odour emission (Sundberg et al., 2004; Sundberg and Jönsson, 2005). Adjusting the pH of food waste by adding alkaline materials such as lime and coal fly ash successfully prevented pH dropping too low and promoted degradation (Bergersen et al., 2009; Wong et al., 2009). However, the risk of nitrogen loss as NH_3 was increased with the addition of lime to raise pH (Sundberg et al., 2004; Wong and Fang, 2000).

Struvite crystallization, which was widely utilized for recovery and reuse of phosphorus (P) and nitrogen (N) in wastewater (Sugiyama et al., 2005; Suzuki et al., 2005), provides an effective countermeasure to achieve nitrogen conservation during

* Corresponding author at: Sino-Forest Applied Research Centre for Pearl River Delta Environment and Department of Biology, Hong Kong Baptist University, Kowloon Tong, Hong Kong Special Administrative Region. Tel.: +852 3411 7056; fax: +852 3411 2355.

E-mail address: jwcwong@hkbu.edu.hk (J.W.C. Wong).

composting (Jeong and Kim, 2001). In our previous study, supplementing salts of magnesium (Mg) and phosphorus (P) to the composting mass buffered the acidity and alleviated the inhibitory low pH conditions during food waste composting and created a suitable environment for microbial degradation (Wang et al., 2013). However, electrical conductivity (EC) of the compost was increased due to the addition of soluble Mg and P salts that not only hampered the decomposition of organic materials, but also negatively influenced the compost maturity (Lee et al., 2009; Wang et al., 2013). The high salinity of compost could lead to plant cell dehydration inhibiting seed germination. Lime addition is an effective technique to alleviate the low pH and improve compost maturity (Wong et al., 2009). However, the microbial and enzyme activities would be reduced if high concentrations of lime are added (Wong and Fang, 2000). Nevertheless, lime addition could control the availability of the soluble salts to contribute to the salinity leading to reduction in EC. Therefore, this study investigated whether the addition of lime could alleviate the salinity problem of struvite based food waste composting and its influence on the struvite formation and nitrogen conservation during composting.

2. Methods

2.1. Food waste and treatment design

A synthetic food waste prepared by mixing bread, rice, cabbage and fully boiled pork in the ratio of 13:10:10:5, as reported before (Wong et al., 2009), was used in this study so as to eliminate the heterogeneity of food wastes allowing reproducible results under different experimental conditions. All the ingredients of the food waste were size reduced to ~1 cm^3 if necessary to ensure a homogeneous mix. The food waste was thoroughly mixed with sawdust at 1.2:1 (w/w dry weight basis) to adjust the C/N ratio to ~30 and the initial moisture content was adjusted to ~55% as reported earlier (Wang et al., 2013; Wong et al., 2009). Selected physicochemical properties of the synthetic food waste are presented in Table 1.

Lime was mixed with raw composting mass at 0.75% (SL0.75), 1.5% (SL1.5), 2.25% (SL2.25) and 3% (SL3) before the addition of magnesium oxide (MgO) and di-potassium hydrogen phosphate (K$_2$HPO$_4$) both at 0.05 M/kg (Wang et al., 2013; Chan et al., 2016) for inducing struvite formation. In the treatment acronym, S represent the struvite indicating the addition of Mg and P salts; while L represents the addition of lime. A control treatment with 2.25% lime alone (L) without struvite salts was also included to evaluate nitrogen conservation efficiency of the struvite based composting treatments.

2.2. Composting and analytical methods

Composting was carried out in a computer controlled 20-L bench-scale reactors, in which the temperature was controlled at 55 °C through a ventilation feedback control system. Detailed setup and operation of the composting process were reported in a previous report (Wong et al., 2009). The reactor temperature was monitored continuously and logged into the computer while the CO$_2$ evolved from the compost reactors was measured on-line using a WMA-2 gas analyzer (PP systems, Herts, UK) with continuous data logging. To measure the NH$_3$ emission, the NH$_3$ in the outlet gas was trapped in boric acid and the concentration was determined titrimetrically (Komilis and Ham, 2000). Aeration was provided at a flow rate of 0.5 L/min/kg (dry weight) through an aerator pump.

The composting mass in each reactor was taken out and mixed thoroughly in a large basin on day 0, 3, 7, 10, 14, 17, 21, 28 and 35 before adjusting moisture back to 55%, while 200 g of well-mixed samples were collected on day 0, 3, 7, 14, 21, 28 and 35 for the analysis pH, EC, extractable ammonium (NH$_4^+$), extractable phosphate, total Kjeldahl nitrogen (TKN) and total organic carbon (TOC) following the standard methods for testing compost materials (TMECC, 2002). Soluble organic nitrogen (SON) and dissolved organic carbon (DOC) were analyzed in the aqueous extract (1:10 w/v dry weight basis). Ammonium extracted using 0.1 M HCl with 1:10 solid to extractant ratio (w/v) was used to quantify the nitrogen fixed in struvite crystals in the compost (Fukumoto et al., 2011). The cress seed germination test was used to assess compost maturity as described by Zucconi et al. (1981) using the following formula:

$$GI\,(\%) = [\text{Seeds germination of compost sample} \\ \times \text{Root length of compost sample}] \\ /[\text{Seeds germination of control} \times \text{Root length of control} \\ \times 100)$$

The degradation of organic matter was calculated using the following formula:

$$\text{Organic matter loss}\,(\%) = 100 - 100\,[X_1(100 - X_2)]/[X_2(100 - X_1)]$$

where, X_1 is the initial organic matter and X_2 is the final organic matter content (Bernal et al., 2009). The ammonia loss (%) was calculated using the following formula:

$$\text{Ammonia loss}\,(\%) \\ = (\text{cumulative ammonia emission/initial total nitrogen}) \times 100.$$

2.3. Data analysis

Analyses were performed with three replicate samples and the mean values with standard deviation are presented on dry weight basis. The data obtained were analyzed using SAS statistical software package (SAS, 2003) and differences between individual means were tested using the Least Significant Difference Test at 5% probability.

3. Results and discussion

3.1. Temperature and CO$_2$ evolution

Food waste contains high quantity of easily degradable organic compounds as reported earlier (Kwon and Lee, 2004). Chemical energy released during the decomposition of complex organic components and active metabolism of microorganism generate lots of heat that raises the temperature drastically during the beginning of composting process (Fig. 1a). Temperatures of Treatments L, SL2.25 and SL3 showed similar trend with an initial high temperature for two weeks before decreasing down to 35 °C till the end of the experiment. However, the thermophilic periods of Treatment SL0.75 and SL1.5 lasted for only around 4 days, indicating that the microbial activity was inhibited in these two treatments.

The microbial activity and composting efficiency are clearly reflected by CO$_2$ evolution rates (Liang et al., 2003; Wong and

Table 1
Selected physicochemical properties of the synthetic food waste, saw dust and the composting mix used in the study.

Parameter	Food waste	Sawdust	Mix
Moisture content (%)	58.2 ± 0.02	7.24 ± 0.03	55.5 ± 1.19
Total organic carbon (%)	45.5 ± 1.70	52.9 ± 0.91	47.0 ± 1.13
Total Kjeldahl nitrogen (%)	3.28 ± 0.04	0.59 ± 0.04	1.41 ± 0.77
C/N$_{solid}$ ratio	13.9 ± 0.35	89.8 ± 4.56	33.7 ± 2.35

Values are mean ± Standard deviation (n = 3).