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Research article

Comparing the effects of three in situ methods on nitrogen loss control, temperature dynamics and maturity during composting of agricultural wastes with a stage of temperatures over 70 °C

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ABSTRACT

The study investigated the effects of three in situ methods for controlling nitrogen loss and maturity with different mechanisms: struvite-based addition (K_2HPO_4 and MgO, MP), woody peat addition (WP) and intermittent aeration (IA), during composting of vegetable waste (cucumber vine) with temperature over 70 °C to inactivate potential viral pathogens. The experiment was conducted in a 200 L pilot-scale composting system, with which temperature and ammonia emission were recorded in real time, and solid samples were collected and analyzed during the process. The results indicated that the methods of MP and IA reduced the total nitrogen loss by 27.5% and 16.1%, respectively, without inhibitory effects on the temperature, nutrient availability and maturity. The WP method significantly decreased the nitrogen loss but could not maintain the thermophilic stage over 70 °C, because of its influence on the material physio-chemical characteristics caused by woody peat addition. In conclusion, all three methods could promote the maturity process, and 20 days should be adequate for vegetable waste composting with a good nutrient availability. Considering the two factors of reducing nitrogen loss and achieving high temperatures together, we recommended the struvite-based controlling method with the mechanism of chemisorption to reduce nitrogen loss during vegetable waste composting that requires temperatures over 70 °C.

1. Introduction

The treatment of vegetable wastes is becoming a major issue worldwide due to its generation in significant quantities, especially in China. Just in the year of 2015 alone, more than 785 million tons of vegetables were produced, followed by more than 360 million tons of vegetable wastes (Chang et al., 2017b). More than 60% of the wastes were abandoned without any treatment, increasing environmental risks for soil, atmosphere and for the plants grown in the soil because of the high moisture, high nutrients and numbers of pathogens contained in vegetable wastes. Aerobic composting provides an effective alternative by stabilizing organic matter and converting the organic waste into a soil conditioner or fertilizer, with a thermophilic stage to inactivate the potential pathogens. However, vegetable wastes may contain viral pathogens, which require a thermophilic stage of over 70 °C during composting for safe utilization in the future (Day and Shaw, 2001; Chang et al., 2017b). While there is a contradiction between the demand and the temperature requirement in hygienic requirements for the safe disposal of night soil (GB7959-2012) used in China, the temperature should be kept over 50 °C for 10 days or over 60 °C for 5 days, and below 70 °C to guarantee that the composting process runs normally. In our previous study, we proved that the temperature could be set above 70 °C by adjusting the initial material with a bulk density of 0.35 $kg\,L^{-1}$ and an easily degraded organic matter percentage of 45% during vegetable waste composting, without any negative effects on composting (Chang et al., 2017a). While the temperature over 70 °C resulted in more ammonia emissions during the thermophilic stage than that of other treatments (Chang et al., 2017b), the high temperatures ($>$ 45 °C) help to shift the NH_4^+ to NH_3 equilibrium towards ammonia (Pagans et al., 2006) and inhibit nitrification at the same time, both of which would increase ammonia volatilization (Nigussie et al., 2017). However, it is still not clear how to reduce the nitrogen loss in our composting process with a thermophilic stage over 70 °C.

A wide range of in situ methods have been studied to reduce nitrogen loss during composting, especially ammonia volatilization: (1) physical adsorption using natural and mineral adsorbents, such as

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biochar addition or additives (Zorpas and Loizidou, 2008; Yañez et al., 2009; Dias et al., 2010; Malińska et al., 2014; Zhang et al., 2015), which increase the total porosity and water holding capacity (Karhu et al., 2011), improving the ratio of macrospores in the structure (Downie et al., 2009), and absorbing the gases to avoid their emission; (2) chemisorption, mostly based on struvite formation by adding Mg salts and PO_4 salts (Jeong and Kim, 2001; Jeong and Hwang, 2005; Lee et al., 2009; Du et al., 2010; Ren et al., 2010; Fukumoto et al., 2015; Wang et al., 2013), which can form an ore material called struvite ($MgNH_4PO_4{\cdot}6H_2O$) and absorb the ammonia produced during composting, named, working as high-quality, slow-release fertilizer when the compost is used in soil; and (3) controlling different aeration frequencies and times (Wang et al., 2011, 2013; Jiang et al., 2015; Zhang et al., 2016a,b), which helps to reduce the amount of ammonia blowing out from the system to conserve the ammonia in the material and give the microbes more time to use and transfer the molecule. While these studies are normally designed to compare the effects of different raw materials, different adding ratios, different additives with similar function, or different scales and positions, few studies have been conducted to compare the three kinds of methods in the same composting system, especially during composting with a temperature over 70 °C. So our overall aim was to compare the effects of the three in situ methods (struvite-based addition as chemisorption, woody peat addition as a physical adsorbent, and intermittent aeration as an aeration controlling method) within the same vegetable waste composting system. The detailed research strategies included the comparisons of: 1) the effects on nitrogen loss and on different forms of nitrogen transformation, and 2) the influence of the methods on the temperature and the process at the same time so that we could choose a suitable method to control the nitrogen loss used in a composting with a stage of temperatures over 70 °C.

2. Material and methods

2.1. Materials preparation

The raw materials (cucumber vines, corn stalks, wheat stalks and chicken manure) were collected from local greenhouse and farmland in Beijing, China. Then, the materials were cut into 2–3 cm pieces to obtain a uniform particle size that enabled good mixing and were set aside. The main characteristics are shown in Table 1. The microbial inoculum used in the experiment was VT inoculum (containing *Brevibacillus laterosporus*, *Bacillus subtilis, Saccharomycetes, Aspergillus niger, Streptomyces microflavus, photosynthetic bacterium, etc.*), which was supplied by Beijing VOTO Biotech Co., Ltd. Dipotassium phosphate (K_2HPO_4) and magnesium oxide (MgO) were purchased from Sinopharm Chemical Reagent Co., Ltd. located in Beijing, and woody peat was supplied by View Sino International, Ltd. located in Hong Kong. All of them were used in powder form.

2.2. Experiment design

The composting experiment was conducted in the lab of the College of Resource and Environmental Science, China Agricultural University.

The four materials (cucumber vines, corn stalks, wheat stalks and chicken manure) were mixed with the ratio of 1: 0.45: 0.55: 0.3 (dry weight basis) to set the initial bulk density of mixed materials as $0.35\,kg\,L^{-1}$ and the easily degraded organic matter percentage as 45%, this was done to realize a temperature of over 70 °C during composting, which was aimed at inactivating the pathogens that may be contained in the vegetable wastes (Chang et al., 2016, 2017b). The total weight of the mixed material was near 53 kg, and the VT microbial inoculum was scattered after mixing the material, to improve the composting process. This mixed material was set as the control (CK). The other three treatments were set used different controlling methods, addition of K_2HPO_4 and MgO (5% of dry weight basis with 1:2 M ratio (Mg:P), designated MP) (Jiang et al., 2016), addition of woody peat (10% of dry weight basis, designated WP) (Zhang et al., 2016a,b), and intermittent aeration (half an hour on followed by half an hour off, designated IA) (Keener et al., 2001). The initial material moisture in the experiment was near 60%, the C/N ratio was approximately 25, and the forced ventilation rate was set $0.2\,L\,min^{-1}{\cdot}kgDM^{-1}$.

Table 1
Characteristics of the materials used for the composting experiment (a ± SD).

Materials	Total carbon/%	Total nitrogen/%	C/N	Lignocellulose/%
Cucumber vine	24.82 ± 1.24	1.22 ± 0.06	20.34	34.11 ± 1.71
Corn stalk	32.04 ± 1.60	0.70 ± 0.04	45.77	70.38 ± 3.52
Wheat stalk	62.35 ± 3.12	0.73 ± 0.03	85.41	50.89 ± 2.54
Chicken manure	37.63 ± 1.88	4.33 ± 0.22	8.69	27.38 ± 1.37

Note: Testing results were shown as average value ± SD.

The 40-day composting experiment was performed in steel reactors (200 L in volume, 1 m high, 0.5 m inner diameter), as shown in Fig. 1, with 5 cm cotton insulation to minimize heat loss. One pump helped to negatively ventilate and the other allowed the gas within the vessel to be sampled. Before the gas was forced to flow into the vessel, two bottles of solution were used to absorb the gases that may influence the analysis of carbon dioxide and ammonia, while the other two bottles of solution were set to absorb carbon dioxide and ammonia from the gas that came out of the vessel. There were five temperature sensors (Pt100) connected with a temperature recorder (SMT-A32): three of them to record the temperature of the material and two for the gas that flowed into and out of the vessel.

During the process, turning was carried out to make sure the material was always mixed well with a suitable porosity. The turning was performed on the days of 0, 3, 7, 12, 17, 22, 27, 32, and 37 by mixing the material outside the reactor.

2.3. Samples collection and analyze

During the process, temperatures were recorded every 30 min by a recorder (SMT-A32) connected to the temperature sensors. The ammonia emission rate and accumulated amount were estimated from the exhaust gas by absorption into a boric acid solution and titration by sulfuric acid (Michałowski and Asuero 2012). The carbon dioxide emission rate and accumulated amount were estimated from the exhaust gas by absorption into a sodium hydroxide solution and titration by sulfuric acid (Malińska et al., 2014).

Solid samples were collected after mixing on the days of 0, 3, 7, 12, 22, and 40. At each sampling procedure, approximately 500 g of solid material was collected from each reactor, repeated 3 times for one treatment. Each sample was thoroughly mixed and then divided into two parts. One part of the sample was air-dried for determination of physicochemical characteristics: total nitrogen (TN), total organic carbon (TOC) and ash content. The other part of the samples was stored in the freezer at −20 °C for determination of other parameters: pH value, Electric Conductivity (EC) and Germination Index (GI), extractable ammonium, water-soluble organic carbon (WSOC).

The TN and TOC were calculated with the methods described in Chinese national standard NY 525-2012. The ash content was determined by ignition in a muffle furnace at 550 °C for 4 h. A 1:5 aqueous extract (w/v, dry basis) of the fresh compost with deionized water was used for the analysis of the pH value, EC, and GI. The pH value and EC were measured using an FE28-TRIS pH meter and FE30 Plus EC meter (Mettler-Toledo). Radish (*Scrophularia ningpoensis Hemsl.*) seeds were used in the seed germination test to evaluate the compost maturity (Chang et al., 2017b). A 1:5 aqueous extract (w/v, dry basis) of the fresh composts with 2N KCl solution was used for the analysis of extractable ammonium ($NH_4{}^{+}$-N), and $NH_4{}^{+}$-N was analyzed by SEAL Analytical (BL-TECH).