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Evaluation of biochar powder on oxygen supply efficiency and global warming potential during mainstream large-scale aerobic composting

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ABSTRACT

This study investigated the effects of biochar powder on oxygen supply efficiency and global warming potential (GWP) in the large-scale aerobic composting pattern which includes cyclical forced-turning with aeration at the bottom of composting tanks in China. A 55-day large-scale aerobic composting experiment was conducted in two different groups without and with 10% biochar powder addition (by weight). The results show that biochar powder improves the holding ability of oxygen, and the duration time (O_2 > 5%) is around 80%. The composting process with above pattern significantly reduce CH_4 and N_2O emissions compared to the static or turning-only styles. Considering the average GWP of the BC group was 19.82% lower than that of the CK group, it suggests that rational addition of biochar powder has the potential to reduce the energy consumption of turning, improve effectiveness of the oxygen supply, and reduce comprehensive greenhouse effects.

1. Introduction

It is estimated that China is at the top of the world's livestock and poultry production with an annual output of nearly 4 billion tons (Dongsheng et al., 2012). Large-scale aerobic composting can effectively handle large amounts of agricultural organic solid waste through high-temperature fermentation to realize harmlessness, minimization, and reclamation of wastes (Bongochgetsakul and Ishida, 2008; de Guardia et al., 2010; Hanc and Dreslova, 2016). However, in large-scale aerobic composting an anaerobic environment easily forms in the presence of low oxygen concentration due to an immense volume of compost materials is involved (Zeng et al., 2016). And as so much organic matter is broken down and degraded, the process of aerobic composting results in large number of emissions of ammonia and greenhouse gas (GHG), which immensely contributes to global greenhouse effects (Colon et al., 2012; Crutzen, 1973). To improve the oxygen supplement and reduce the GHG emission in the large-scale aerobic composting process, the composting pattern and addition were involved and investigated.

The common pattern of large-scale aerobic composting are static, bottom ventilation, and turning (Haug, 1993). Some researchers investigated the effect of pattern on GHG and oxygen supplement. Generally, the composting process can be defined as an aerobic condition when pore oxygen concentration exceeds 5 vol% (Haug, 1993). Zeng et al. (2016) found that only regular turning couldn't realize that the pore oxygen concentration exceeds 5 vol% and the compost was in low aerobic condition. Ahn et al. (2011) found that GHG emissions from random turning compost piles were higher than those from static piles. Relatively speaking, regular turning relative to static compost can effectively reduce GHG, ammonia, and other gas emissions (Nasini et al., 2016; Puyuelo et al., 2014). Similarly, straw-rich pig manure with a low carbon nitrogen ratio (C/N) could be composted directly without significant GHG and ammonia emissions if turned periodically in higher frequency (Szanto et al., 2007). Thus, an adequate oxygen concentration and reasonable pattern were also found to be beneficial to the degradation of organic matter and reduction of GHG emissions (Ahn et al., 2011; Bongochgetsakul and Ishida, 2008; Chowdhury et al., 2014; Nasini et al., 2016; Puyuelo et al., 2014; Szanto et al., 2007). The composting pattern, which is cyclical forced-turning with aeration at the bottom of the composting tank, has become mainstream for waste degradation in China. However, there are also several problems with aerobic composting, especially including local anaerobic phenomenon and abundant GHG emissions.

In recent years, biochar has been widely used in the aerobic composting process due to its high stability, developed pore structure, and abundant surface functional feature groups, which could provide nutrition for compost, fix nitrogen and carbon elements, and reduce GHG emissions (Awasthi et al., 2016; Chen et al., 2017; Chowdhury et al., 2014; Dias et al., 2010; Liu et al., 2017; Sanchez-Garcia et al., 2015; Tao, 2014; Zhang et al., 2014). Chen et al. (2017) explored the effects of different kinds of biochar on the form of nitrogen and CH_4 and ammonia emissions during laboratory-scale aerobic composting and found

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that biochar, which has a particle size greater than 0.5 cm, could reduce emissions. Liu et al. (2017) analyzed different additive amounts of bamboo biochar with particle sizes between 3 and 5 cm and determined that it could significantly reduce GHG emissions in laboratory-scale reactor systems. The centimeter-level biochar required large size materials. It was not suitable for large-scale composting condition that required to use abundant biochar. In China, there is a large amount and many varieties of crops straw, which has an annual output of nearly 900 million tons (NBSC, 2016; Niu et al., 2016; Yuyun, 2010), and biochar powder based on straw is easier to produce than the biochar particles. Yet, there are limited studies on the application and potential of biochar powder in mainstream large-scale aerobic composting in China, which is combination of periodic mechanical turnover and intermittent bottom ventilation.

In an effort to solve problems of low oxygen supply and production of greenhouse gas in the aerobic composting process used on a large-scale in China, the biochar powder was mixed into composting materials. This paper investigates the oxygen supply, greenhouse gas effects, and application potential of adding biochar powder into the cyclical forced-turnover large-scale aerobic composting with intermittent bottom ventilation. To quantify the reduced ability of biochar, we calculated the Global warming potential (GWP) in the large-scale aerobic process. GWP is a relative measure of how much heat a greenhouse gas traps in the atmosphere by comparing the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide. The GWPs of CH_4 and N_2O are about 25 times for CH_4 and 296 times for N_2O, in a time horizon of 100 years which is commonly used by regulators (IPCC, 2015). Meanwhile, we also analyze the effectiveness of biochar in improving the oxygen supply efficiency and reducing the effect of comprehensive greenhouse gas, combined with microscopic and mesoscopic-scale characterization analyses. Accordingly, our results provide data and methodological support to optimize the current large-scale aerobic composting process, energy saving methods, emission reduction, and quality improvement of compost.

2. Materials and methods

2.1. Large-scale aerobic composting experiment with addition of biochar powder

2.1.1. Composting materials

Fresh pig manure (PM) was obtained from the Beilangzhong pig farm (Beijing, China), and dry chicken manure (CM) was collected from the Charoen Pokphand Group chicken farm (Beijing, China). Rice straw (RS) (≤10 cm) was collected from No. 291 farm located in Heilongjiang province of China. Rice straw biochar powder (RSB) was bought from Nanjing Qinfeng Stalks Co., Ltd (Jiangsu Province, China), which was produced based on rice straw by slow pyrolysis at 500 °C in an atmosphere without oxygen. According to the suitable range of initial moisture content (MC) from 55% to 60% and initial C/N ratio around 10, we use the dry chicken manure and rice straw to adjust the initial composting mixture by using a fork-lift truck. In the previous lab-scale experiment, 10% is a proper content for the addition of biochar powder (Liu et al., 2017). Thus, two groups of experiments were conducted separately in two composting tanks, where one did not contain biochar powder (CK group) and the other had biochar powder that was added by the weight rate of 10% (BC group). The compounding ratio of CK and BC were PM:CM:RS = 10:10:1 and PM:CM:RS:RSB = 10:10:1:1, respectively, and the total weight of both were approximately 20 tons. The basic physicochemical properties of raw materials and initial mixture are shown in Table 1. Meanwhile, the percentage of oxygen element and sulfur element were respectively 43.28 ± 5.8% and 0.88 ± 0.20%.

2.1.2. Experimental design

The composting experiment was conducted in adjacent fermenting tanks, which were 44 m in length, 3.8 m in width, and 1.86 m in height in an organic fertilizer plant located in the Shunyi district of Beijing, China. The initial height of the piles is 1.5 m. The shape of composting piles is cuboid. The self-propelled turnover could mix and move the mixture 4 m in length, so that the composting pile could be divided into 11 sections along the length direction. As the fork-lift truck transported composting material out of the tank by deeply shoveling into the bottom of the piles, the first and last sections were not laid with aeration pipelines. Therefore, composting piles from section 3 to 9 were ventilated with 8 pipes using two air blowers. The experimental process adopted intermittent circulation ventilation with an aeration time of 15 min/h, the continuous cycle was performed 12 h every day, and turnover occurred once every two days.

The duration of the aerobic composting process was a total of 55 days. The monitoring points designed at the specific sections of porous oxygen concentration and temperature. The composting temperature in both composting piles which totals 12 points in different layers and ambient temperature were automatically monitored and documented at 5-min intervals using a Pt100 temperature sensor (0–100 °C, ± 0.1 °C) and programmed data acquisition system (DT85, DataTake Pty Co. Ltd, Germany), marked as T and Ta, respectively. The oxygen concentration was recorded in different layers of composting piles before and after aeration using oxygen sensor (Biogas, Gaetch, UK), which was performed twice per day at 8:30 am and 16:00 pm, marked as O_2.

On days 0, 2, 4, 6, 9, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 51, and 55, considering the vertical space differences, 1 kg sample was respectively collected in the top (4/5 height of total piles), middle (1/2 height of total piles), and bottom (1/5 height of total piles) layers by a soil sampler (ZYA-10D, Shangke Instruments Co. Ltd, China). Samples were immediately frozen at −4 °C until further analysis.

The emissions of CH_4 and N_2O in the composting process were determined by static closed chamber-gas chromatography (Tao, 2014). The height and diameter of the static closed chamber were 30 cm and 25 cm, respectively. The gas samples were extracted and stored into gas bag (Delin, China), then tested by gas chromatograph (Agilent 7890, America) within 10 days. Gas sampling was performed under 3 different conditions, which were before aeration, after aeration, and 10 min after turning. The temperature of samples was recorded at corresponding times of these conditions following the collection of gas samples from the static closed chamber.

2.2. Analytical methods and calculations

2.2.1. Conventional physicochemical properties

Organic matter (OM) and moisture content (MC) were measured according to the Test Method for the Examination of Composting and Compost (Council, 2002). Using the elemental analyzer (Elemental Vario EL, Germany), total carbon (TC) and total nitrogen (TN) were determined to calculate the C/N ratio.

Based on the ratio of solid to liquid ratio of 1:10 (w/v), 10 g fresh sample and 100 mL deionized water were mixed in 30 min at 250 rpm and then centrifuged for 30 min (3200 rpm). Using a pipette after centrifugation, 5 mL supernatant was extracted into a petri dish that was covered by one piece of filter paper with a regular arrangement of 10 cucumber seeds (Zhongnong 26 invented by the Institute of Vegetables and Flowers Chinese Academy of Agricultural Sciences, IVFCASS). Next, each petri dish was incubated at 30 °C for 48 h without any light before germination index (GI) and root length determinations. Each determination was performed in duplicate using deionized water as the control. The formula for calculating GI is as follows (Li and Peng, 2011):