Bioresource Technology 266 (2018) 82–88

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Influence of clay as additive on greenhouse gases emission and maturity evaluation during chicken manure composting

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ARTICLE INFO

Keywords:
Greenhouse gas
Composting
Maturity
Clay
Chicken manure

ABSTRACT

To assess the impact of clay as additive on compost maturity and reduction of greenhouse gases (GHGs) as well as ammonia emission during chicken manure composting. Six treatments with different dosages of clay (0%, 2%, 4%, 6%, 8% and 10% clay added by dry weight basis of chicken manure and wheat straw) were designed to conduct an aerobic composting experiment for 50 days. The results showed that the clay amendment could prolong the thermophilic phase and reduced the maturity period of composting. In addition, the GHGs (N_2O and CH_4) and ammonia emission of clay added treatments were reduced by 25.3–63.4%, 26.01–50.24% and 8.5–70.5%, respectively. But CO_2 emission was significantly higher in 10% clay amended treatment. Furthermore, the redundancy analysis showed that C/N ratio and total organic matter among all physiochemical properties had significant relationship with GHGs and ammonia emission. Therefore, this study shown that clay addition can promote maturity, reduced GHGs emission and improve the quality of product.

1. Introduction

In China, due to the rapid development of chicken farms, the output of chicken manure (CM) has risen sharply in the past decade. The over production and accumulation of untreated CM has caused a series of environmental and social problems (Shi et al., 2018). While, as an available organic waste, the CM has a high concentration of macro and micro nutrients among all livestock manure. Therefore, the cost effective waste-recycling technologies need to find to convert CM into fertilizer. In this regard, aerobic composting is considered as an effective way to manage livestock manure because mature compost application can improve soil fertility and promote plant growth (Hageman et al., 2018).

However, unsuitable composting could result in emission of greenhouse gases (GHGs) which is harmful to atmosphere and could also cause other series of relevant environmental problems (Mao et al., 2018; Szanto et al., 2007). Many researchers also confirmed that the loss of nitrogen caused by N_2O emission during the composting could reach 0.09–3.8% (Fukumoto et al., 2006), and the production of CH_4 accounts for about 0.8–6% of the total carbon mass of compost (Wolter et al., 2004; Hao et al., 2004). According to the report of IPCC, the global warming potential (GWP) of CH_4 and N_2O are 25 (CH_4) and 298 (N_2O) times higher compared to CO_2, respectively, on a 100-year frame (IPCC, 2007). In addition, the ammonia (NH_3) emission is also the main reason for nitrogen loss during the composting, which is the volatilization of ammonia accounts for about 20–60% of the total nitrogen loss (He et al., 2005; Pagans et al., 2006; Petersen and Sommer, 2011). Therefore, to improve the composting engineering by the amendment of organic and inorganic additives has great significance which is not only reduce the emission of GHGs and NH_3 during the composting but the same time also mitigate the mobility of heavy metals and other essential nutrients (Awasthi et al., 2017b; Mao et al., 2018). There are more than thousands research papers has been published with different types of additives to reduce the GHGs and NH_3 emission last one decade such as, Awasthi et al. (2016a) studied a conclusion that higher amount of zeolite mixed with lime could decrease the maximum GHGs and NH_3 emission and improve quality of the composting end product, which is consistent with the result of Belyaeva and Haynes (2009). In addition, many researches also have been confirmed the effect of different amendments such as lime (Fang et al., 1999; Wong et al., 2009), zeolite (Awasthi et al., 2016a; Chan et al., 2015), bentonite (Wang et al., 2016), medical stone (Wang et al., 2017a,b; Awasthi et al., 2018) and biochar (Li et al., 2017a,b; Zhang et al., 2014; Awasthi et al., 2017a,b) and coal fly ash (Belyaeva and Haynes, 2009) as proper additives for various organic waste composting, which all could mitigate the emission of NH_3 and GHGs but also conserved the nutrients.

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https://doi.org/10.1016/j.biortech.2018.06.073
Received 10 May 2018; Received in revised form 21 June 2018; Accepted 22 June 2018
0960-8524/

Clay is a low-cost and widely distributed porous mineral which is mainly composed by montmorillonite and kaolinite. But none of study reported with the amendment of clay to improve the CM composting which is not only promote porosity and aeration of the compost, but also improve water absorption and encourage microbial activities. Therefore, the purpose of this experiment was to study 1) the effect of various quantities of clay to the physical and chemical characteristics of CM composting; 2) the effect of the clay additive for mitigation of NH_3 and GHGs emission during CM composting; 3) finally the influence of clay amendment into the end product quality.

2. Materials and methods

2.1. Materials collection and processing

The experiment was carried out at Northwest Agriculture and Forestry University campus. The CM used in this study was obtained from a local chicken farm (Yangling, Shanxi Province, China) and the wheat straw (WS) was purchased from local market. The WS was added to adjust the ratio of C/N and also as a kind of loosening agent to fortify the porosity of composting. WS was chopped into 1 cm^{-1} length before mixing by the using of pulverized to get uniform particle size. The clay used in this experiment was collected from the sediment of the local mountain. The depth of collection is 3–4 m in the middle of the mountain and then grinded to pass 0.15 mm sieve, mixed before use. The major mineral components of clay are montmorillonite and kaolinite and the clay particles percent content is about to 70%, thus this kind of nature clay can be considered to represent clay material to be used as composting amendment to improve the CM composting. The selected properties of each raw material are shown in Table 1.

2.2. Experimental design and methods

Six of 100 L PVC container which could protect the temperature and control aeration condition were chosen to perform this experiment. The details of composter structure and operation were shown previously (Awasthi et al., 2017a). The CM and WS were mixed with the ratio of 5:1 (fresh weight basis) to ensure the ratio of C/N was 30 and added proper deionized water to maintain moisture content to 60%. Then clay was added to the initial feed stock in proportions of 2%, 4%, 6%, 8% and 10% on dry weight of CM and WS basis, respectively, while treatment without clay was carried out for control. Subsequently, 1 kg of plastic sphere was mixed with initial composting mass to adjust the 0.5 kg/L bulk density to according to Awasthi et al. (2015). Deionized water was added on turning over days to keep the optimum moisture content (60%) throughout the experiment. After fully mixing, each reactor was filled with 100 L initial feed stock and composted for 50 days. The composting was turned over and mixed properly prior to collection on 0, 3, 7, 14, 21, 28, 35, 42, 50 days. The collected samples were segregated into two part; one portion was preserved at 4 °C before analyses while the other was freeze-dried at −20 °C. Temperature was monitored by thermos probe fixed in middle of the reactor every 12 h. The environmental temperature was also tested.

Table 1
Characteristics of composting materials used in this study.

Parameters	CM	WS	Clay
Moisture content (%)	78.56 ± 0.12	9.23 ± 0.01	3.87 ± 0.002
TKN (%)	2.395 ± 0.04	4.59 ± 0.03	0.11 ± 0.01
OM (%)	69.74 ± 0.89	90.96 ± 1.12	2.46 ± 0.01
pH	6.77 ± 0.01	7.11 ± 0.01	7.06 ± 0.01
EC (μS/cm)	6280 ± 25	113.4 ± 8	90.5 ± 6

CM – Chicken manure, WS – Wheat straw, EC – Electrical conductivity, TKN – total Kjeldahl nitrogen and OM – Organic matter. Results are the average of three repeats ± standard deviation.

2.3. Analytical methods

The NH_3 was analyzed by the standard method (Hao et al., 2004). The samples of GHGs (CO_2, CH_4 and N_2O) were collected and tested according to previous method Awasthi et al. (2016a). The results were shown as gram of N or C/time (d). The pH and Electrical conductivity (EC), NH_4^+-N, total organic carbon (TOC), and total Kjeldahl nitrogen (TKN) were analyzed according to standard test methods (TMECC, 2002). The phytotoxicity level was also identified by seed germination index (SGI) (Zucconi et al., 1981).

2.4. Statistical analysis

The analyses of all treatments were repeated three times and all figures were drawn by using origin 2016. Statistical analysis was carried out to compare the LSD at $p < 0.05$ level by making use of SPSS 18.0 software. The Redundancy analysis (RDA) was used to study the correlation between GHGs, NH_3 and other physiochemical properties by Canoco 5.

3. Results and discussions

3.1. Changes of temperature and pH during composting

Temperature is one of the key indicators to reflect the organic matter degradation and microbial activity of the composting. The temperature of reactor achieves 55 °C within 5–7 d and maintains more than 3 d which is one of the most important conditions to kill the pathogenic microorganisms and ensure compost hygiene indicators (Yang et al., 2013). The dynamic change of the temperature during this study is shown in Fig. 1a, which whole process can be normally divided into three stages: thermophilic stage, mesophilic stage and maturation stage, the value ranged from 24.5 to 70 °C. All of the composting experiments have similar temperature distribution patterns. This kind of increasing trend represented speedy degradation of materials and active microbial activities which could be due to existent of abundant of easily available organic matters (Wang et al., 2017a,b). RDA also confirmed that temperature has a significant relationship with NH_3 emission and organic matter degradation, this shows in all treatments especially in 8% and 10% clay added treatments, nevertheless, GI and TKN showed a negative correlation with temperature (Fig. 4). Compared with CK, the addition of clay increased the temperature of the composting mass. With the amount of clay dosages increased, the days which temperature of each treatment maintained above 50 °C were also increased. CK, 2%, 4%, 6%, 8% and 10% maintained a temperature of 50 °C for 16, 17, 17, 18, 19, and 20 days, and the maximum temperatures of each treatment were 66 °C, 66.5 °C, 67 °C, 67 °C, 70 °C and 70 °C, respectively. These findings are in keeping with the previous results of Li et al. (2017a,b), who added the different proportions of bamboo charcoal (0%, 5%, 10%, and 20% on dry weight basis) for chicken manure composting. The result showed that the treatments applied 8% and 10% clay entered the thermophilic phase earlier and also extended the duration compared with the CK, this situation was due to the addition of clay which could improve the ventilation of the composting mass and ensure adequate oxygen content. Thus microbial activity was more active, so that the decomposition reaction of material was more intense and as results produced more heat. However, the data not presented here but moisture content is also an important factor which significantly affected the composting mass temperature.

The addition of 8% and 10% clay kept the moisture content of the composting mass within an appropriate range, which reduced the heat loss by evaporation of water. Due to the turning over in day 14, the temperature of all treatments went down and then rose again in next day. From day 20, the temperature of all treatments gradually declined and tended to surrounding temperature. Besides, a temperature recovery appeared three times and then decreased to the ambient