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Effects of biochar amendment on ammonia emission during composting of sewage sludge

Krystyna Malińska[a,*], Magdalena Zabochnicka-Świątek[a], Jacek Dach[b,1]

[a] Institute of Environmental Engineering, Częstochowa University of Technology, Brzeźnicka 60a, 42-200 Częstochowa, Poland
[b] Faculty of Agronomy and Bioengineering, Poznań University of Life Sciences, Wojska Polskiego 50, 60-637 Poznań, Poland

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ABSTRACT

The presented research included laboratory scale composting of sewage sludge and woodchips mixtures amended with biochar in 45 L reactor system conducted for 16 days. The effect of biochar amendment on ammonia emission was investigated. The addition of biochar reduced significantly volatilization of ammonia during the first week of the process. Also, the addition of biochar increased temperature and organic matter decomposition.

1. Introduction

Composting is a widely used cost-effective and socially acceptable method for treating solid or semisolid biodegradable waste (Külcü and Yaldiz, 2014). It allows for the conversion of waste materials (including biowaste, agricultural residues, sewage sludge, etc.) into stabilized compost—an organic fertilizer and value added product (Haug, 1995; Piotrowska-Cyplik et al., 2013; Boniecki et al., 2013). However, not all biodegradable waste materials are suitable for composting without further treatment or amendment. Composting of materials with high N content and low C/N ratio results in ammonia volatilization which in turn leads to N losses in composted materials. Nitrogen in materials subjected to composting is one of the most important factors that influence the quality of final composts. The release of ammonia is due to the decomposition of nitrogenous material and occurs in the thermophilic stage of composting (Sánchez-Mondereo et al., 2001; Villaseñor et al., 2011). Loss of nitrogen through ammonia volatilization during thermophilic phase is considered a significant problem in composting (Chen et al., 2010). Transformation of nitrogen during composting is strongly affected by a number of factors such as C/N, moisture content, composition of substrates and initial composting mixtures, temperature and pH, bulking agents and aeration rates (Haug, 1995; de Guardia et al., 2008; Waszkielis et al., 2013).

There have been a number of studies on the fate of nitrogen in composting of various materials with high nitrogen content such as poultry litter (Ogunwande et al., 2008; Steiner et al., 2010), manure, organic fraction of municipal waste and household waste (Eklind and Kirchmann, 2000; Beck-Friis et al., 2001; Sánchez-Mondereo et al., 2001) and sewage sludge (Sánchez-Mondereo et al., 2001; Czyżyk and Rajmund, 2009; Dach et al., 2009; Dach, 2010a, 2010b; Kalembasa and Wysokiński, 2011). Nitrogen transformation during composting is complex and occurs mostly through mineralization, volatilization, nitrification, immobilization and denitrification (Haug, 1995). Nitrogen loss during composting mostly results from gaseous emissions of NH_3, N_2O, N_2 and NO_x compounds. Most studies indicated that NH_3 emissions predominated during composting of various organic materials causing significant nitrogen losses. Beck-Friis et al. (2001) studied gaseous emissions during organic household waste composting. They found that nitrogen emissions consisted of more than 98% of ammonia and 2% of nitrous oxide. Ammonium can be volatilized as ammonia (high temperatures and pH above 7.5) or immobilized by microorganisms in composted materials preventing from nitrogen loss through ammonia volatilization (Dias et al., 2010). It is estimated that emissions of ammonia during proper composting should not exceed 10–12% of total nitrogen loss (Dach, 2010b). According to the results from the studies on nitrogen

* Corresponding author. Tel.: +00 48 34 3250 917x30/+00 48 695 659 327.
E-mail address: kmalinska@is.pcz.czest.pl (K. Malińska).
1 Tel.: +00 48 61 848 7156.

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transformation the loss of nitrogen during composting of different organic waste varies and can constitute even more than 70% (Beck-Friis et al., 2001; Czyżyk and Rajmund, 2009). Czyżyk and Rajmund (2009) observed the loss of total nitrogen during windrow composting of sewage sludge mixed with woodchips (C/N 20:1) of 47.8% after 120 days and 58.2% after another 8 months. Ogunwande et al. (2008) observed cumulative nitrogen loss during composting of poultry litter between 71% and 88%.

Many researchers studied different methods to reduce emissions of ammonia and loss of nitrogen during composting. They investigated a wide range of bulking agents, bedding materials, microorganisms and various amendments such as natural and mineral adsorbents (Malińska et al., 2004; Zorpas and Loizidou, 2008; Dach et al., 2009; Yañez et al., 2009; Dias et al., 2010; Lim et al., 2010; Dach, 2010a; Doublet et al., 2011; Malińska and Zabochnicka-Świątek, 2013). One of these amendments is biochar.

Biochar is produced in a thermal conversion of plant biomass, organic waste, sewage sludge and even algae biomass (Bird et al., 2011) with other liquid and gaseous products with high potential for energy production (Verheijen et al., 2009; Matovic, 2011). Recent practices show that production of biochar from a wide range of agricultural waste can be a farm-based approach to recover energy and recycle organic waste (Malińska, 2012). Depending on biomass type and process parameters of a thermal conversion of biomass, biochar can consist of 50–90% of organic carbon, 1–15% of moisture content, 0–40% of volatile substances and 0.5–5% of mineral ash. C/N ratio can range from 7 to 500 or more. Biochar has neutral or alkali pH. The contents of P and K in various biochars are different and the content of P and K in biochars is 2.7–480 g/kg and 1.0–58 g/kg, respectively (Verheijen et al., 2009). According to the numerous literature references the addition of biochar to soils improves soil fertility and climate changes due to sequestration of carbon in soil and reduction of N_2O and CH_4 from soils. It also increases water holding capacity and soil pH, prevents from nutrient leaching and binds organic and inorganic contaminants (Lehman and Joseph, 2009). Due to its properties biochar can be used in composting to reduce nitrogen loss, increase the total porosity and water holding capacity (Karhu et al., 2011). Biochars produced from various lignocellulosic materials during slow pyrolysis have high ratio of macrospores in the structure (Downie et al., 2009) that are filled with air and allow for maintaining aerobic conditions in soil (Van Zwieten et al., 2009). Dias et al. (2010) investigated the effect of eucalyptus biochar application for composting of poultry manure. They observed that the addition of biochar allowed for optimization of the process by reduction of odors and nitrogen losses. Steiner et al. (2010) also investigated the process of composting poultry manure and biochar. The addition of biochar to poultry manure facilitated the biodegradation kinetics and reduced the emissions of ammonia by 64%. These researchers concluded that biochar can be an ideal amendment for composting of waste rich in nitrogen.

The overall goal of this paper is to study the effect of biochar amendment on ammonia emissions and nitrogen loss during composting of sewage sludge mixed with woodchips. It has been hypothesized that the addition of biochar to composting mixtures prepared from sewage sludge and woodchips may have an effect on emission of ammonia and nitrogen loss during composting. Biochar has a potential for composting applications, e.g. as an amendment it can increase water holding capacity, prevent from nutrient leaching, bind organic and inorganic contaminants, and also reduce nitrogen losses during composting. The objective of this work was to evaluate the effect of biochar for reduction of ammonia emission and nitrogen loss during composting in laboratory scale reactors.

2. Material and methods

Materials used in the laboratory experiment included: sewage sludge (SS), woodchips (WC) and biochar (B) (produced from woody material). Sewage sludge was sampled from the *Warta Wastewater Treatment Plant* in Częstochowa, Poland. The characteristics of sewage sludge (MC = 81.2%, OM = 62.0%, N = 3.1%, C/N = 11:1, pH = 7.68) were in the range typically observed in the literature. Air-dried woodchips (MC = 16.7%, OM = 95.9%, N = 1.5%, C/N = 35:1, pH = 6.9) were obtained from a local farm and biochar commercially available in stores. Biochar as an amendment and woodchips as a bulking agent with strong absorbing properties were used for preparation of composting mixtures. Air-dried biochar (MC = 4.9%, OM = 92.6%, N = 0.26%, C/N = 242:1, pH = 7.1) was crushed into fine particles. Sewage sludge and woodchips were mixed in the ratio of 1:0.3 (wet weight) whereas the ratio for the mixtures amended with biochar was 1:0.2:0.05 (wet weight). The mixtures amended with biochar were run in two replications and presented as separate treatments. The ratio of sewage sludge and a bulking material was selected to obtain minimum C/N ratio required for composting and the addition of biochar (i.e. 4%) was one of the lowest reported in the literature. In practice, the addition of amendments such as bulking agent and biochar depends on availability and price.

The experiment was conducted for 16 days in 45 L composting reactors equipped with the aeration system (constant aeration rate of 3 L/min), the thermocouple, CO_2 and NH_3 traps with 1 N NaOH and 1 N H_2SO_4, respectively. Composting of the investigated mixtures (ca. 20 kg) in the reactors was monitored daily for CO_2, NH_3 and temperature. Composting mixtures were mixed periodically and samples were taken for analysis of moisture content (MC), organic matter content (OM), Kiejdahl nitrogen and pH. Moisture content, organic matter content and pH were analyzed in triplicates whereas CO_2, NH_3 and Kiejdahl nitrogen in duplicates using standard laboratory procedures.

3. Results and discussion

3.1. Characteristics of mixtures

Characteristics of mixtures with sewage sludge, woodchips and biochar amendment are presented in Table 1. Moisture content of the mixtures of sewage sludge and woodchips with the addition of biochar was between 70.9 and 68.3%. The mixture SS:WC showed C/N of 20:1. Generally, the addition of biochar to sewage sludge and woodchips increased the content of organic matter and organic carbon, and thus increased C/N ratio. The pH of all mixtures was between 7.04 and 7.25.

3.2. Laboratory-scale composting

Composting of SS + WC and SS + WC + BC (in two replications) was daily monitored for ammonia and carbon dioxide emissions and temperature. Ammonia emission during composting of SS + WC and SS + WC + BC is presented in Fig. 1. Generally, the highest emissions were observed during the first week of composting. Also, during the first week the emission of ammonia was significantly lower in the mixtures with the addition of biochar. After mixing and sampling the materials in the reactors (on day 8) the emission of ammonia decreased and shortly after increased again in case of all mixtures. However, during the second week of composting the emission of ammonia was higher from the mixtures with the addition of biochar.