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Heterogeneity of biochar amendment to improve the carbon and nitrogen sequestration through reduce the greenhouse gases emissions during sewage sludge composting

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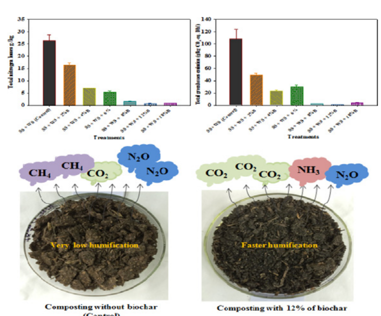
HIGHLIGHTS

- Biochar additions increased the dehydrogenase activity during composting.
- Biochar have a potential impact on reduction of N losses and gaseous emissions.
- Biochar amendments shorten the thermophilic phase period.
- Biochar additions increased CO_2 emission and reduce the ammonia losses.
- Biochar additions have significant correlation with carbon and nitrogen losses.

GRAPHICAL ABSTRACT



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ABSTRACT

This study was performed to investigate the effects of biochar as an amendment to a gaseous emissions and sewage sludge (SS) composting dynamics. Six dosage of biochar [low dosage of biochar (LDB) – 2%, 4% and 6%; and higher dosage of biochar (HDB) – 8%, 12% and 18%] were amended to a mixture of SS and wheat straw (4:1 ratio on dry weight basis) and compared to control or without additive. The HDB significantly reduced CH_4, N_2O and NH_3 emission by 92.85–95.34%, 95.14–97.30% and 58.03–65.17%, but not the CO_2 emission. Meanwhile, humification results indicated that humic and fulvic acid 35–42% and 24–28% higher in the HDB amended treatments than those in the LDB and control treatments. The HDB significantly decreased total nitrogen losses and greenhouse gas emission, while LDB had significantly ($p < 0.001$) higher CH_4 and N_2O emissions. Due to effective performance of HDB, the 12% biochar was recommended to be used in SS composting practice.

1. Introduction

Nowadays, greenhouse gas (GHG) emissions from various anthropogenic organic waste management processes are attracted the attention of environmental scientists because of the growing concerns on global warming (Chen et al., 2010). Recently, Bong

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et al. (2016) has reviewed the influence of different waste management strategies on GHG emissions and emphasis the side-effect of the emissions during organic waste composting and mitigation strategies. However, one of the major part of GHG emission is carbon dioxide (CO_2) which represent 63%, whereas methane and nitrous oxide produced 24% and only 3%, respectively (Luo et al., 2013; Jiang et al., 2016). But particular CH_4 and N_2O emission have a high warming potential, 30 and 210 times higher than CO_2 (IPCC, 2007). The huge quantity of CO_2 is generated during organic matter degradation, but its global warming influence is negligible as compare to CH_4 and N_2O for the evaluation of the impact of waste management practices because CO_2 evolutions are of biogenic origin (IPCC, 2007; Awasthi et al., 2016b). In consequence, some developing countries e.g. China is one of the highest populated country and produced huge quantity (30 million tons/year) of putrescible characteristics of sewage sludge (SS) from different wastewater treatment plants, and its ecofriendly management by traditional composting process generated extensive quantity of GHG (Zhang et al., 2014; Awasthi et al., 2016c). Therefore, increasing the demand for improving and expansion of composting strategies with the formulation of novel feedstock to reduce not only CH_4 and N_2O emission, but also mitigate significant amount of CO_2 production and total nitrogen as well as carbon loss during various kinds of organic waste composting.

In order to control global warming, recently several earlier researchers have applied to reduce the CH_4 and N_2O emission during various organic waste composting employing different bulking agents like saw dust, agricultural wastes (Szanto et al., 2007; Zhang et al., 2014) and amended with different kinds of mineral additives such as lime, zeolite, bentonite and medical stone (Li et al., 2012; Awasthi et al., 2016b,c; Wang et al., 2016). But no any previous study reported to reduce CO_2 emission combined with other gases like NH_3, CH_4 and N_2O, because huge quantity of CO_2 emission and less amount of other gases such as NH_3, CH_4 and N_2O can cause secondary pollution and reduces the environmental benefits of compost. Consequently, these gases emission combined together contribute to maximum organic nutrient loss from the end product and also lower the quality of the compost. However, CO_2 emission is inevitable during composting when the organic matter mineralization and the temperature and pH are high (Zhang et al., 2014; Jiang et al., 2016; Awasthi et al., 2016b), while CH_4 and N_2O emission are significant GHG. But previous studies have proved that more than 30–40% of total organic carbon, 70–74% of initial total nitrogen (TN) is lost during organic waste composting (Beck-Friis et al., 2000; Fukumoto et al., 2003). Among these, most TOC is lost in form of CO_2 emission (Awasthi et al., 2016c,d), while 10–46% of TN is lost in the form of NH_3 (Sanchez-Monedero et al., 2010; Luo et al., 2013; Wang et al., 2016) and 0.1–10% is lost in the form of N_2O (Shen et al., 2011; Awasthi et al., 2016b). The CH_4 emission is a byproduct of anaerobic degradation during the composting but can be substantially reduced the emission with proper aeration and addition of bulking agent. Beside this, Sommer and Moller (2000) has reported that between 0.01% and 0.03% of the initial total organic carbon (TOC) may be lost in the form of CH_4, when settlement of composting mass and then some anaerobic pockets formed inside.

Recently, wheat straw biochar production and its amendment for SS composting is considered to be as cost effective and ecofriendly technology with successful composting (Malinska et al., 2014; Jiang et al., 2016; Awasthi et al., 2016b), because biochar has excellent ability to adsorbs GHG, and ammonia as well as increases the humification of organic waste (Dias et al., 2010; Jindo et al., 2012; Chowdhury et al., 2014). Consequently, last few years several earlier researchers observed that biochar amendment led to faster mineralization and reduced total GHG emission by 42.8% during the poultry manure composting (Dias et al., 2010; Chowdhury et al., 2014), while Chen et al. (2010) and Jiang et al. (2016) reported that ~45 to 55% GHG emission reduction pig feces and pig manure mixed with struvite salt and coffee husk biochar. But most of previous studies have only focused on CH_4, N_2O and NH_4 reduction employing biochar as amendment for various types of organic waste materials composting (Steiner et al., 2010; Wang et al., 2013; Bong et al., 2016), while CO_2 and ammonia losses are another problematic issue. Therefore, we hypothesized that biochar amendment into mixture of feed stock will be provide various benefits during the SS composting. Because porous micro-structure of biochar leads to provide optimal aeration as per indigenous microbial demand and not only reduce the CH_4 and N_2O emission, but act as biofilter to decreased the CO_2 and ammonia losses (Chen et al., 2010; Sonoki et al., 2013), consequently biochar amendment alleviate the initial low pH during the thermophilic stage of composting (Wei et al., 2014; Czekala et al., 2016). Remarkably, from an extensive literature search and conclude that no previous studies reported reduction of CO_2 combined with CH_4 and N_2O emission as well as its relationship with humification. Therefore, the purpose of the present study was (i) to evaluate heterogeneity of biochar for total organic carbon loss mitigation through CO_2 and CH_4 emission and nitrogen conservation by N_2O and NH_4 reduction, and as consequence to determine the most effective dosage biochar for SS composting; (ii) to study the relationship between the mechanisms involved in the total gaseous emission, carbon, nitrogen losses and humification of the composting mixtures.

2. Materials and methods

2.1. Raw materials collection and processing

The SS and wheat straw were used as raw materials in this investigation. SS was obtained from a local municipal wastewater treatment plant (Yangling, Shaanxi Province, China) and wheat straw (WS) was taken from the local agricultural farm research station of Yangling Northwest A&F University. Wheat straw biochar (WSB) was purchased from Yangling Pvt. Ltd., Shaanxi Province, China. To achieve the appropriate moisture content (~55%) and C/N ratio ~25, SS and WS were mixed at a ratio of 4:1 (dry weight basis). In addition, 1 kg of plastic spheres was mixed with initial feed stock to adjust the initial bulk density to ~0.5 kg/L according to our previous work experience (Awasthi et al., 2016a). Air dried WSB was crushed into fine particles and sieved to 2–5 mm; and then used as an amendment for composting, while the characteristics of raw materials are shown in Table 1.

2.2. Experiment design and compost sample collection

The composting process was performed in polyvinyl chloride (PVC) reactors, each with a total working volume of 130-L under controlled ambient temperature; and systematic layout of the

Table 1
Selected physicochemical properties of raw materials used in the present experiments (dry weight basis).

Parameters	SS	WS	WSB
Moisture content (%)	82.10 ± 2.17	12.86 ± 0.26	3.30 ± 0.08
pH (solid:water = 1:5)	7.18 ± 0.06	4.93 ± 0.10	8.83 ± 0.12
EC (mS cm^{-1}) (solid:water = 1:5)	5.36 ± 0.12	0.89 ± 0.02	1.05 ± 0.04
Total organic matter (%)	79.30 ± 2.18	98.38 ± 2.31	95.60 ± 2.17
Total organic carbon (%)	42.72 ± 2.13	58.14 ± 1.04	65.08 ± 1.10
Total Kjeldahl nitrogen (%)	2.70 ± 0.06	0.80 ± 0.03	0.58 ± 0.02
C:N ratio	15.82 ± 0.14	72.70 ± 1.20	112.2 ± 4.31

ND – Not detected, SS – Sewage sludge, WS – Wheat straw, WSB – Wheat straw biochar and EC – Electrical conductivity. Results are the mean of three replicates ± standard deviation.