

# Effect of biochar on nitrogen loss control and the change of bacterial populations in sewage sludge composting

Mukesh Kumar Awasthi<sup>1,2</sup>, Quan Wang<sup>1</sup>, Meijing Wang<sup>1</sup>, Hongyu Chen<sup>1</sup>, Zengqiang Zhang<sup>1\*</sup>

<sup>1</sup>College of Natural Resources and Environment, Northwest A&F University, Yangling, Shaanxi Province 712100, PR China

<sup>2</sup>Department of Biotechnology, Amicable Knowledge Solution University, Satna, India

\* Presenting author email: [mukesh\\_awasthi45@yahoo.com](mailto:mukesh_awasthi45@yahoo.com)

## Abstract

The aim of this study was to evaluate the effect of different dosage of biochar on nitrogen loss and greenhouse gases (GHGs) emission control and the change of bacterial populations in sewage sludge composting. Seven concentration of biochar (0%, 4%, 6%, 12% and 18%) were applied into the composting experiments conducted in the lab-scale reactor. The variation in temperature, pH, GHGs, nitrogen content and bacterial population related to nitrogen transformation were detected during the 42 days composting. The addition of higher dosage of biochar reduced nitrogen loss and denitrifying bacteria population while increased the population of ammonifying, ammonia assimilating and nitrifying bacteria. Nitrogen loss was reduced by 34.7%, 42.3% and 46.5% in 8%, 12% and 18% biochar added treatments, respectively. The population of ammonifying, ammonia assimilating and nitrifying bacteria increased by 7.8–23.5%, 2.6–17.2%, 3.5–18.5%, respectively. The 12% biochar was the optimal amendment due to the lowest nitrogen loss (7.80%), the highest population of ammonia assimilating (7.5 log<sub>10</sub>cfu/g) and nitrifying bacteria (6.8 log<sub>10</sub>cfu/g). The results suggested that adding higher dosage of biochar in sludge composting could reduce nitrogen loss through improving the population of ammonifying, ammonia assimilating, nitrifying bacteria and reducing the population of denitrifying bacteria.

**Keywords:** Sewage sludge; greenhouse gases; composting; nitrogen loss; biochar.

## 1. Introduction

Composting, a traditional sanitization process used for sewage sludge treatment, involves the recycling of nutrients and their re-use as a biofertilizer for organic farming. But greenhouse gases (GHGs) emissions from various anthropogenic organic waste management practices one of the major problem and attracted the attention of environmental scientists because of the growing concerns on global warming (Chen et al., 2010; Awasthi 2016a). Recently, Bong 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. Although, one of the major part of GHGs emission is carbon dioxide (CO<sub>2</sub>) 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<sub>4</sub> and N<sub>2</sub>O emission have a high warming potential, 30 and 210 times higher than CO<sub>2</sub>, respectively (IPCC, 2007). The huge quantity of CO<sub>2</sub> is generated during organic matter degradation, but its global warming influence is negligible as compare to CH<sub>4</sub> and N<sub>2</sub>O for the evaluation of the impact of waste management practices because CO<sub>2</sub> evolutions are of biogenic origin (IPCC, 2007; Awasthi et al., 2016 b). 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 GHGs (Zhang et al., 2015; Awasthi et al., 2016 c). Thus increasing the demand for improving and expansion of composting strategies with the formulation of novel feedstock to reduce not only CH<sub>4</sub> and N<sub>2</sub>O emission, but also mitigate significant amount of CO<sub>2</sub> 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<sub>4</sub> and N<sub>2</sub>O 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<sub>2</sub> emission combined with other gases like NH<sub>3</sub>, CH<sub>4</sub> and N<sub>2</sub>O, because huge quantity of CO<sub>2</sub> emission and less amount of other gases such as NH<sub>3</sub>, CH<sub>4</sub> and N<sub>2</sub>O can cause secondary pollution and reduces the environmental benefits of compost. Therefore, the objective of the present study was to develop an efficient GHGs mitigation and nitrogen conservation during composting with the assistance of wheat straw biochar (WSB). For this purposes two specific aspects were focused: investigating the temporal gaseous emission profile during sewage sludge composting amended with wheat straw biochar; and the effect of supplying different dosages of WSB to the system.

## 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. 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, 1kg 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., 2016 a). Air dried WSB was crushed into fine particles and sieved to 2-5 mm; and then used as an amendment for composting and the characteristics of raw materials are shown in our previous study (Awasthi et al., 2017).

### 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 100-L under controlled ambient temperature; and systematic layout of the reactor and operational process is already described in our previous study (Li et al., 2012). Seven treatments were conducted in triplicate to evaluate the effect of biochar at 4%, 6%, 12% and 18% (on SS dry weight basis) to determine the best optimum dosage of biochar for GHG emission reduction with special emphasis to decreased the CO<sub>2</sub> emission and TOC as well as nitrogen losses. The SS+WS without any additives amendment was used as control for comparison purpose. About 100-L of each mixture was composted for 56 days in a reactor. Moisture content of the composting mixture was readjusted to 55% periodically on turning days 0, 3, 7, 10, 14, 21, 28, 35, 42, 49 and 56; meanwhile about 250g compost samples were collected from each treatment for further analysis. Fresh samples were separated into three parts; one part was air dried, properly ground, sieved through 0.1mm sieve and then used for total nutrients content analysis, while two other parts were stored as fresh sample on 4°C and -20°C for chemical and microbiological analysis. The composting biomass temperature was monitored every day four times (6h) by the using of thermocouple probe inserted into the center of the composting materials and averaged temperature was reported, respectively. Despite this the room temperature was also recorded. The thermocouple, air inlet and outlet pipes were disconnected from the reactor when the composting mass was turned and mixed.

### 2.3. Greenhouse gases and compost analysis

The GHGs and ammonia gas was collected, and analyzed according our previous study (Awasthi et al., 2016a). Moisture content was determined by oven drying at 105°C till constant weight basis. Fresh compost samples 1:5 aqueous extract (dry weight basis) was used for the analysis of pH, electrical conductivity (EC), extractable ammonium (NH<sub>4</sub><sup>+</sup>-N) and germination index (GI). The pH and EC were measured using pH meter with a glass electrode (INESA PHSJ-3F, China) and conductivity electrode (INESA DDS-307, China). Total organic matter (TOM), NH<sub>4</sub><sup>+</sup>-N, total Kjeldahl nitrogen (TKN) and total organic carbon (TOC) were determined as per the standard Test Methods for the Examination of Composts and Composting (TMECC, 2002). All the physic-chemical and microbial analyses were performed in triplicate. Meanwhile data were subjected on the basis of two-way analysis of variance (ANOVA) and multiple comparison tests were also performed to compare the least significance difference (LSD) at  $p = 0.05$  values using SPSS v.21 software package for windows.

## 3. Results and discussion

### 3.1. Effect of biochar amendment on temperature and pH

For higher dosage of biochar (HDB) amended (6%, 12% and 18%) treatments, the temperatures sharply increased at the beginning of composting and exceeded more than 60°C within 3 days (Fig. 1a), which reflect rapid degradation of organic waste. The thermophilic phase lasted around 2 weeks and then gradually decreased with the deficiency of easily available degradable organic matter; this bio-oxidation phase is long enough to destroy the pathogenic microbes and weeds seeds (Zhang et al., 2014; Awasthi et al., 2016b). When compare to the 4% of biochar applied treatment, the thermophilic phase in this trial is significantly later and shorter, possibly low dosage of biochar application cannot accelerate the degradation of organic matter from the beginning of composting process; and its thermophilic phase lasted only four to five days as well as temperature never go more than 55 °C. In contrast, without biochar added or control treatment showed very low temperature through the composting process and never go more than 50 °C, which could be attributed due to low pH and higher moisture content (data not shown). The lower pH and higher moisture content not only inhibit the composting process, but also increase the anaerobic clumps, volatile organic acids (VOAs) and NH<sub>4</sub><sup>+</sup>-N formation in the composting feedstock that further decrease the degradation of organic matter and accelerate the GHGs emission as well as cause odor problems (Steiner et al., 2010; Sánchez-García et al., 2015; Awasthi et al., 2016 a).

The pH of the initial feedstock was slightly alkaline in all biochar amended treatments than their initial values or control treatment (Fig. 1b). LDB (4%, and 6%) added treatments were showed slightly acidic pattern of pH during the early phase of composting and HDB (12% and 18%) amended treatments showed neutral range of pH profile with a rapid activation of composting process, while control treatment showed acidic pH through the

composting process (Fig.1b). Consequently, the results indicated that HDB addition (12% and 18%) adequately buffer the VOAs production during the thermophilic phase. Beside this, 4% biochar applied treatment resulted low buffering ability during the thermophilic phase of composting and as consequence low microbial activities, and low CO<sub>2</sub> emission was observed at the beginning of composting (Fig. 2a). This fact is in line with the previous studies using biochar as amendment or co-substrate for various kind organic waste composting (Wang et al., 2013; Wei et al., 2014; Czekala et al., 2016).

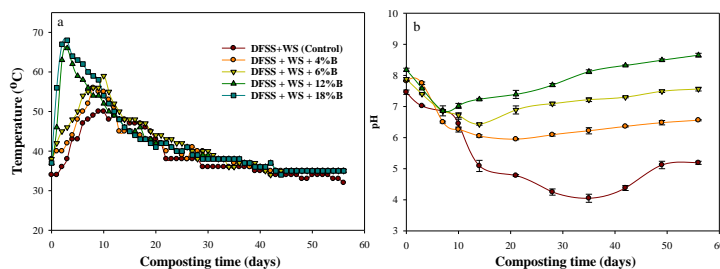


Fig.1.Changes in temperature (a) and pH (b) from different treatments during composting of sewage sludge.

### 3.2. Effect of biochar amendment on gaseous emission

From the beginning of the composting period, CO<sub>2</sub> emission was higher in the HDB amended treatment. The maximum CO<sub>2</sub> emission (67.55 g/day) was observed, and the emissions gradually decreased thereafter until the end of the thermophilic phase (week 3). The lowest CO<sub>2</sub> emission was observed during the maturation phase, which reflects the stability of the mature compost. In addition, low CO<sub>2</sub> emissions and high CH<sub>4</sub> emissions were observed in the control (82.60 gCH<sub>4</sub>-C/kg composting mass) and 4% biochar (37.38 gCH<sub>4</sub>-C/kg composting mass) amended treatments, which clearly indicates the development of anaerobic pockets in both of these composting treatments. This inhibitory effect was also reflected in the temperature and pH profiles of both treatments. The HDB amendment resulted in a low CH<sub>4</sub> emission 12% and 18% biochar (0.85 to 0.45 gCH<sub>4</sub>-C/kg composting mass) and a high CO<sub>2</sub> emission (Fig. 2a-b). The CH<sub>4</sub> and CO<sub>2</sub> emission profiles were consistent with previous studies, and the underlying reason for the profile shape has been well explained (Beck-Friis et al., 2001; Sanchez-Monedero et al., 2010; Santos et al., 2016).

The maximum ammonia emission was observed in the 4 and 6% amended treatment (Fig. 2c). In contrast, ammonia emission in the control treatment comparatively very low throughout the composting process might be due to slow degradation of organic matter, and it could not be considered as an ammonia loss. A maximum of 20% to 22% of TKN was lost in the form of ammonia from 4 and 6% amended treatment; while less than 6%-8% of TKN was lost from the 12 to 18% biochar applied treatment (Fig. 2c) at the end of composting. The NH<sub>3</sub> emission profiles from our study were generally consistent with several previous studies (Luo et al., 2013; Malinska et al., 2014; Sanchez-Garcia et al., 2015) but were higher than the result reported in Szanto et al. (2007), in which 2.5-3.9% of TKN was lost in the form of ammonia with a 4% biochar amendment.

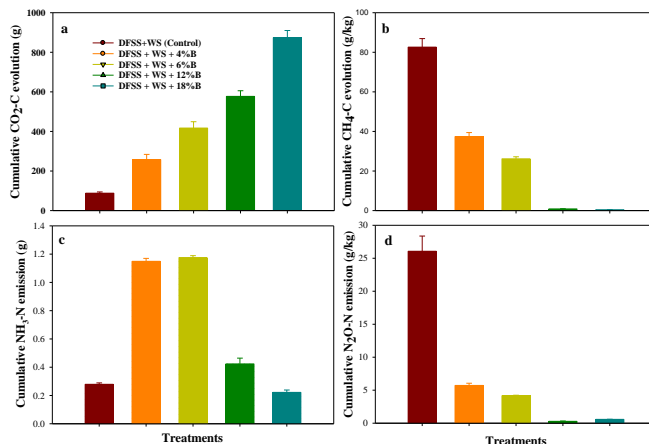


Fig. 2. Cumulative carbon dioxide (a), methane (b), ammonia (c) and nitrous oxide (d) emission from different treatments during composting of sewage sludge.

The maximum N<sub>2</sub>O emission was observed in the control treatment and considerable amounts from 4 to 6% biochar applied treatments (Fig. 2d) and then gradually decreased thereafter; this finding clearly indicates the presence of anaerobic pockets in control treatment and 4 to 6% biochar applied treatments from the beginning of composting and may be the result of composting feed stock settlement reducing the O<sub>2</sub> availability. These anaerobic

pockets formed despite the forced air ventilation and turning events supplied to all treatments to eliminate the anaerobic pockets in the composting matrix. Very low  $\text{N}_2\text{O}$  emissions were observed in the 12 to 18% biochar amended treatment, which might be due to the rapid mineralization of organic matter, low nitrate concentration during the bioactive phase (data not shown) or dominant  $\text{NH}_4^+\text{-N}$  concentration (Fig. 1e). During the thermophilic phase of composting,  $\text{N}_2\text{O}$  emissions seemed to be responsible for a relevant fraction of TKN losses in the control and lime amended treatments, as shown in Fig. 2d. Similar findings were also obtained in previous studies (Szanto et al., 2007; Maulini-Duran et al., 2014; Awasthi et al., 2016a,b), where the proportion of bulking agent, mixing of additives and turning frequency of the composting mass were key factors in regulating the GHG emissions and nitrogen losses.

### 3. Conclusions

12% Biochar applied treatments considerably reduced the  $\text{NH}_3$ ,  $\text{CH}_4$  and  $\text{N}_2\text{O}$  emission by 58.03-65.17%, 92.85-95.34% and 95.14-97.28% as compare to control treatments, respectively. Although, the 4% biochar addition has slightly lower  $\text{NH}_3$  emission than control, but its low pH was not adequately buffered the compost, and then inhibited the composting process. Furthermore, it is estimated that 12% biochar can reduce the length of the active phase and enhance the organic matter mineralization with significant reduction of total N loss and GHG emissions. Overall, the addition of 12% biochar for composting demonstrated to be a beneficial practice for the SS management.

### 4. Acknowledgment

The authors are grateful for the financial support from the China Postdoctoral Science Foundation (No. 2016M602865) and post-doctoral scholarship from Northwest A&F University (No. 154433). We are also thanks to our all laboratory colleagues and research staff members for their constructive advice and help.

### 5. References

- Awasthi, M.K., Wang, M., Chen, H., Wang, Q., Zhao, J., Rena, X., Li, D.S., Awasthi, S.K., Shen, F., Li, R., Zhang, Z., 2017a. Heterogeneity of biochar amendment to improve the carbon and nitrogen sequestration through reduce the greenhouse gases emissions during sewage sludge composting. *Bioresour. Technol.* 224, 428–438.
- Awasthi, M.K., Wang, Q., Huang, H., Li, R., Shen, F., Lahori, A. H., Wang, P., Guo, D., Guo, Z., Jiang, S., Zhang, Z., 2016a. Effect of biochar amendment on greenhouse gas emission and bio-availability of heavy metals during sewage sludge co-composting. *J. Clean. Prod.* 135, 829–835.
- Awasthi, M.K., Wang, Q., Rena, X., Zhao, J., Huang, H., Awasthi, S.K., Lahori, A.H., Li, R., Zhang, Z., 2016b. Role of biochar amendment in mitigation of nitrogen loss and greenhouse gas emission during sewage sludge composting. *Bioresour. Technol.* 219, 270–280.
- Beck-Friis, B., Pell, M., Sonesson, U., Jönsson, H., Kirchmann, H., 2000. Formation and emission of  $\text{N}_2\text{O}$  and  $\text{CH}_4$  from compost heaps of organic household waste. *Environ. Monit. Assess.* 62, 317–331.
- Fukumoto, Y., Osada, T., Hanajima, D., Haga, K., 2003. Patterns and quantities of  $\text{NH}_3$ ,  $\text{N}_2\text{O}$  and  $\text{CH}_4$  emissions during swine manure composting without forced aeration-effect of compost pile scale. *Bioresour. Technol.* 89, 109–114.
- IPCC, 2007. Climate change 2007- The physical science basis. Contribution of working group I to the fourth assessment report of the IPCC. Cambridge University Press.
- Jiang, T., Ma, X., Tang, Q., Yang, J., Li, G., Schuchardt, F. 2016. Combined use of nitrification inhibitor and struvite crystallization to reduce the  $\text{NH}_3$  and  $\text{N}_2\text{O}$  emissions during composting. *Bioresour. Technol.* 217, 210–218.
- Li, R., Wang, J.J., Zhang, Z., Shen, F., Zhang, G., Qin, R., Li, X., Xiao, R., 2012. Nutrient transformations during composting of pig manure with bentonite. *Bioresour. Technol.* 121, 362–368.
- Malinska, K., Zabochnicka-Swiatek, M., Dach, J., 2014. Effects of biochar amendment on ammonia emission during composting of sewage sludge. *Ecol. Eng.* 71, 474–478.
- Sanchez-Monedero, M.A., Serramia, N., Civantos, C.G., Fernandez-Hernandez, A., Roig, A., 2010. Greenhouse gas emissions during composting of two-phase olive mill wastes with different agro-industrial by-products. *Chemosphere* 81, 18-25.
- Steiner, C., Das, K.C., Melear, N., Lakly, D., 2010. Reducing nitrogen loss during poultry litter composting using biochar. *J. Environ. Qual.* 39 (4), 1236–1242.
- Szanto, G.L., Hamelers, H.V.M., Rulkens, W.H., Veeken, A.H.M., 2007.  $\text{NH}_3$ ,  $\text{N}_2\text{O}$  and  $\text{CH}_4$  emissions during passively aerated composting of straw-rich pig manure. *Bioresour. Technol.* 98, 2659–2670.
- TMECC (Test Methods for the Examination of Composts and Composting), 2002. In: Thompson, W., Leege, P., Millner, P., Watson, M.E. (Eds.), *The US Composting Council*, US Government Printing Office <<http://tmecc.org/tmecc/index.html>>.
- Wang, Q., Wang, Z., Awasthi, M. K., Jiang, Y., Li, R., Ren, X., Zhao, J., Shen, F., Wang, M., Zhang, Z. 2016. Evaluation of medical stone amendment for the reduction of nitrogen loss and bioavailability of heavy metals during pig manure composting. *Bioresour. Technol.* 220, 297-304.

Zhang, J., Lu, F., Shao, L., He, P., 2014. The use of biochar-amended composting to improve the humification and degradation of sewage sludge. *Bioresour. Technol.* 168, 252–258.