Journal of Sustainable Bioenergy Systems, 2015, 5, 56-61
Published Online June 2015 in SciRes. http://www.scirp.org/journal/jsbs
http://dx.doi.org/10.4236/jsbs.2015.52005

Short Report: Effects of Biochar Addition on Manure Composting and Associated N_2O Emissions

Xingyong Jia[1,2], Wenqiao Yuan[2*], Xiaotang Ju[1]

[1]College of Resources and Environmental Sciences, China Agricultural University, Beijing, China
[2]Department of Biological and Agricultural Engineering, North Carolina State University, Raleigh, NC, USA
Email: [*]wyuan2@ncsu.edu

Received 4 February 2015; accepted 12 May 2015; published 14 May 2015

Abstract

Recent interests in biochar stem from its agronomic benefits and carbon sequestration potentials in soil applications. As a not fully understood newer concept, adding biochar as a bulking agent to animal manure composting has the potential to enhance the performance of composting process and reduce associated N_2O emissions. This short report presents emerging trends and knowledge gaps in this research area, and provides an introduction to understand the mechanism by which biochar impacts manure composting performance and N_2O fluxes.

Keywords

Manure Composting, Biochar, N_2O Emission

1. Introduction

Nitrous oxide (N_2O) is a potent greenhouse gas that contributes to global warming, climate change, and stratospheric ozone depletion [1]. Globally averaged N_2O concentration in the air in 2012 reached 325.1 ppb, which was 120% of the pre-industrial level (270 ppb) [2]. Agriculture has been one of the major sources of global N_2O emissions. Emissions from soil and associated nitrogen (N) inputs, such as synthetic fertilizer, animal manure and crop residue, are the main agricultural N_2O sources, contributing 90% of the total [3]. Mosier *et al.* [4] estimated that animal manure applied to soils directly contributed 0.3 Gt CO_2-eq/yr (*i.e.*, 10%) to global N_2O emissions. Nitrogen losses in the form of N_2O from land application of animal manure are of global and regional importance to air quality and climate change [5].

[*]Corresponding author.

How to cite this paper: Jia, X., Yuan, W. and Ju, X. (2015) Short Report: Effects of Biochar Addition on Manure Composting and Associated N_2O Emissions. *Journal of Sustainable Bioenergy Systems*, **5**, 56-61.
http://dx.doi.org/10.4236/jsbs.2015.52005

As an alternative to direct land application, composting is one of the widely accepted technologies for recycling organic wastes in agriculture: it can minimize some of the disadvantages associated with direct application of raw wastes, e.g., phytotoxicity, leaching and denitrification of mineralized organic N [6]. Composting consists of the transformation of organic matters (OM) into a relatively well-stabilized product through rapid succession of microbial populations under aerobic conditions. During that process, part of the OM is mineralized to CO_2, whereas the rest is transformed to humic substances, which represent a valuable index of OM stabilization [7]. However, the emission of greenhouse gases from composting of organic wastes is a serious problem. For example, annual global N_2O emissions from composed organic wastes have been estimated at 1.2×10^6 metric tons or approximately 0.4 Gt CO_2-eq [8]. At this scale, composting poses serious environmental risks by contributing to global warming and ozone depletion. When applied to soils, composted manure is also known to increase N_2O emissions by stimulating nitrification and denitrification [9]. Compared with N_2O emissions from chemical fertilizers, N_2O emissions from manure are of greater duration and emission intensity [10].

The authors believe that one solution to the above challenges is to compost animal manure with biochar and apply this composted biochar-manure (CBM) to soils to enhance crop production and minimize N_2O emission. Biochar is charcoal produced from biomass via pyrolysisor gasification [11] [12]. Biochar can effectively retain NH_3, NH_4^+, and NO_3^- in animal manure [11]. Recent studies demonstrated that bulking manure with biochar reduced N loss while simultaneously enhancing humification, thereby producing mature composts with a high fertilizer value [13]-[16].

2. The Formation of N_2O during Manure Composting

Composting of high organic content wastes has been shown to produce N_2O by the microbial processes of nitrification and denitrification, and N_2O generation is found to depend on the transformation of different nitrogen states in the composting mixture [1]. As shown in **Figure 1**, under aerobic conditions, NH_4^+-N from manure is rapidly converted into N_2O by incomplete nitrification. But at the conditions of low O_2 contents, NO_3^--N in the manure emits N_2O through incomplete denitrification process [17] [18]. Considering the shortage of oxygen for most composting piles, denitrifiation is responsible for the most part of N_2O generation in composting, while nitrification makes a substantial contribution to the N_2O emission at the surface of composting pile where O_2 is adequate and temperature is suitable [19].

Manure properties such as moisture content, NO_x-N content and carbon-to-nitrogen ratio (C:N) along with process management such as aeration, temperature regime, turning, covering and compacting can significantly affect N_2O emissions during composting [20]. For example, it was found that there were large amounts of N_2O emissions during the early stage of composting with high N materials because of NO_x-N denitrifying in the early stage. Conversely, at this period, nitrification that limits N_2O emission is restricted owing to the unsuitable microbial activities at the environment of high temperature and nitrogen/oxygen [21] [22]. The research in dairy

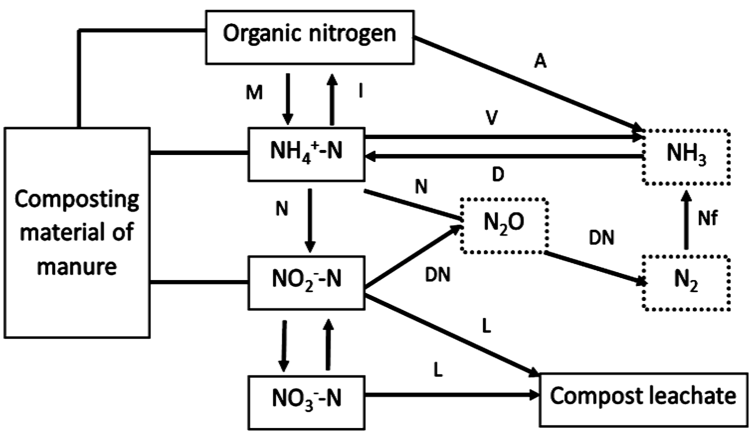

Figure 1. Nitrogen transformation during manure composting (adopted from [18]). A: Ammonification; I: Immobilization; M: Mineralization; V: Volatilization; D: Dissolution; Nf: N-fixation; N: Nitrification; DN: Denitrification; L: Leaching loss.

cattle manure and swine waste composting confirmed that the cumulative emissions of N_2O increased significantly by the use of mature compost that contains nitrate and nitrite [17] [23]. In general, materials with a low C:N is desirable for low N_2O emission composing [24] [25]. Moisture content in composting mixtures is another important parameter affecting the quality of the compost because it affects the metabolic and physiological activities of microorganisms. High moisture content enhanced nutrient transport [24], but too high moisture may cause anaerobic conditions, which provides the beneficial conditions to generate N_2O through the incomplete denitrification pathway of NO_x-N. It also prevents and halts the ongoing composting activities [24] [26]. On the other hand, very low moisture content would cause early dehydration during composting and becomes a limiting factor for the aerobic degradation, thus giving physically stable but biologically unstable composts [24]. In general, 50% - 60% moisture content is identified as suitable for effective composting and inhibiting N_2O emission [24] [27].

In addition to manure properties, various environmental variables also affect composting and its N_2O emission. Temperature of the composting process is widely considered as a significant factor for composting efficiency and N_2O emission because microbial metabolism and activities are all temperature sensitive and dependent. It was found that temperature of composing below 20˚C or in excess of 60˚C would slow and even stop composting owing to impeded microbial activity [24], which explains why there was lower or even no generation of N_2O during the thermophilic phase (temperature of higher than 50˚C) in the early stage of composting [28]. Substantial N_2O emissions usually start in the middle stage of composting when the temperature of the composting pile begins to decline [29]. Aeration is another important factor because composting is basically an aerobic transformation of organic matters where O_2 is necessary, and the supply/distribution of O_2 in the composting pile also affects the production and emission of N_2O. Usually, with increasing O_2 the emission of N_2O increases first and then decreases, therefore proper aeration is beneficial for reduction of N_2O emissions [27] [30]. Similarly, controlling the air void of the composting pile through compacting or adding porous materials affects N_2O emission [27]. Besides, other factors such as pile size, pH and available nutrients have also been shown to impact on composting performance and N_2O emission [24] [29].

3. Biochar in Manure Composting and Its Effect on N_2O Emissions

The mechanisms of N_2O formation described in Section 2 can help us understand the effect of biochar addition in manure composting. The authors believe that biochar, produced from high carbon content solid biomass, is one of the best bulking agents for reducing N_2O emission in manure composting for the following reasons. First of all, its high porosity results in increased aeration in the composting process, which enhances the supply and distribution of O_2 in the composting pile, and may lead to reduction of N_2O as previously mentioned reasons [16]. Secondly, the high porosity and high surface area of biochar also enables it to absorb and retain large amounts of water which results in decreased N_2O emission by altering redox conditions and denitrifying communities. High moisture content also enhances the metabolic and physiological activities of microorganisms by transporting dissolved nutrients [12] [24]. Thirdly, NH_3 or water-soluble NH_4^+, adsorbed by biochar significantly reduces NH_3 and NO_3^- losses during composting, further to reduce the emission of N_2O, which also offers a mechanism for developing slow release fertilizers [31]. Steiner *et al.* [11] incorporated biochar to poultry manure and composted them over a 42-d period, and found that NH_3 emissions decreased by 47% - 55% as the rate of biochar incorporation increased, confirmed that biochar was effective to alter N transformation and fate. These beneficial effects may have been caused by the decrease in N availability for denitrification, as biochar can efficiently adsorb and retain ammonia gas and ammonium as well as nitrate ions [32] [33]. Furthermore, other recent studies confirmed that bulking poultry manure with biochar lessened N loss and improved N retention, while simultaneously enhanced humification, thereby produced mature composts with a high fertilizer value [11] [34] [35]. Fourthly, biochar with a higher pH alters the abundance of denitrifying bacteria significantly in manure composting, resulting in less N_2O producing but more N_2O-consuming bacteria communities [12]. Although the benefits regarding the use of biochar as a bulking agent for composting have been demonstrated, research in understanding its role in reducing N_2O emission is still scarce. The mechanism by which biochar impacts N_2O fluxes over the entire composting period is also poorly defined.

In addition to the reported results of biochar reducing N_2O emission in manure composting, biochar also provides benefits on accelerating composting. For example, it not only provides structural support to prevent the physical compaction of the pile and increases air voids allowing the aeration of the pile [36], but also acts as a biodegradable carbon and energy source for supporting microbial activity and balancing the initial C:N ratio of the mixture [37]. Besides, the addition of biochar to the composting process can reduce the activity of methanogen (CH_4 production) and increase methylotroph (CH_4 oxidation) activity of microbes. Moreover, non-carbon neutral CO_2 can be mitigated by the strong carbon sequestration ability of biochar, which is beneficial for reducing the environmental load of GHG emissions [16].

The question on how manure interacts with biochar and alters biochar properties is scientifically interesting, though currently little is known. For example, composting may facilitate surface oxidation of biochar by the elevated temperature, especially at the beginning of the composting process. It also changes biochar properties biotically by the high microbial activity or the co-metabolic decay during the degradation of available carbon sources [38] [39]. In addition, the nutrient contents of biochar can be enriched by co-composting with nutrient-rich manure. Biochar absorbs leachate generated during the composting process, resulting in increased moisture content. With the leachate, biochar also absorbs organic matter and nutrients, resulting in increased contents of water-extractable organic carbon, total soluble nitrogen, plant-available phosphorus and plant-available potassium, therefore increasing nutrient retention capability of the composted material. However, it should be noted that the surface area of biochar might decline during the composting process due to the clogging of micropores by adsorbing compost-derived material [40]. Besides, the sorption of organic matter like humic acid from manure could lead to an increase of oxidized functional groups, e.g., carboxylic groups, on the biochar surface, which further increases surface oxidation and absorptivity [32]. Thus, co-composting manure with biochar is considered a promising method that can generate a nutrient- and humus-rich soil amendment agent or slow release fertilizer [35] [41].

4. Conclusion

With limited literature available, biochar has demonstrated its potential in enhancing manure composting and reducing associated N_2O emissions. This can be attributed to the high porosity and high surface area of biochar that enables absorption/adsorption and retention of water, NH_3 or water-soluble NH_4^+, as well as nitrate ions, leading to desirable metabolic and physiological activities of microorganisms. The authors believe that co-composting manure with biochar is a promising method for both slow-release fertilizer production and greenhouse gas mitigation; however, further research is needed to understand the role of biochar in the composting process and the interaction between manure, biochar, and microbes.

Acknowledgements

This work was financially supported by the startup fund of North Carolina State University.

References

[1] Bouwman, A.F. (1990) Exchange of Greenhouse Gases between Terrestrial Ecosystems and the Atmosphere. In: Bouwman, A.F., Ed., *Soils and the Greenhouse Effect*, John Wiley and Sons, New York, 61-127.

[2] World Meteorological Organization (2013) Greenhouse Gas Bulletin. World Meteorological Organization, Geneva.

[3] Organisation for Economic Co-Operation and Development (2008) Environmental Performance of Agriculture in OECD Countries since 1990. OECD Publishing, Paris, 576.

[4] Mosier, A., Kroeze, C., Nevison, C., Oenema, O., Seitzinger, S. and Van Cleemput, O. (1998) Closing the Global N_2O Budget: Nitrous Oxide Emissions through the Agricultural Nitrogen Cycle-OECD/IPCC/IEA Phase II Development of IPCC Guidelines for National Greenhouse Gas Inventory Methodology. *Nutrient Cycling in Agroecosystems*, **52**, 225-248. http://dx.doi.org/10.1023/A:1009740530221

[5] Petersen, S.O., Sommer, S.G., Béline, F., Burton, C., Dach, J., Dourmad, J.Y. and Mihelic, R. (2007) Recycling of Livestock Manure in a Whole-Farm Perspective. *Livestock Science*, **112**, 180-191. http://dx.doi.org/10.1016/j.livsci.2007.09.001

[6] Butler, T.A., Sikora, L.J., Steinhilber, P.M. and Douglass, L.W. (2001) Compost Age and Sample Storage Effects on Maturity Indicators of Biosolids Compost. *Journal of Environmental Quality*, **30**, 2141-2148. http://dx.doi.org/10.2134/jeq2001.2141

[7] Senesi, N. and Plaza, C. (2007) Role of Humification Processes in Recycling Organic Wastes of Various Nature and Sources as Soil Amendments. *CLEAN-Soil, Air, Water*, **35**, 26-41. http://dx.doi.org/10.1002/clen.200600018

[8] Czepiel, P., Douglas, E., Harriss, R. and Crill, P. (1996) Measurements of N_2O from Composted Organic Wastes. *En-*

vironmental Science Technology, **30**, 2519-2525. http://dx.doi.org/10.1021/es950841j

[9] Chadwick, D., Sommer, S., Thorman, R., Fangueiro, D., Cardenas, L., Amon, B. and Misselbrook, T. (2011) Manure Management: Implications for Greenhouse Gas Emissions. *Animal Feed Science and Technology*, **166**, 514-531. http://dx.doi.org/10.1016/j.anifeedsci.2011.04.036

[10] Rochette, P., Angers, D.A., Chantigny, M.H., Gagnon, B. and Bertrand, N. (2008) N_2O Fluxes in Soils of Contrasting Textures Fertilized with Liquid and Solid Dairy Cattle Manures. *Canadian Journal of Soil Science*, **88**, 175-187. http://dx.doi.org/10.4141/CJSS06016

[11] Steiner, C., Das, K.C., Melear, N. and Lakly, D. (2010) Reducing Nitrogen Loss during Poultry Litter Composting Using Biochar. *Journal of Environmental Quality*, **39**, 1236-1242. http://dx.doi.org/10.2134/jeq2009.0337

[12] Wang, C., Lu, H., Dong, D., Deng, H., Strong, P.J., Wang, H. and Wu, W. (2013) Insight into the Effects of Biochar on Manure Composting: Evidence Supporting the Relationship between N_2O Emission and Denitrifying Community. *Environmental Science and Technology*, **47**, 7341-7349. http://dx.doi.org/10.1021/es305293h

[13] Ishizaki, S. and Okazaki, Y. (2004) Usage of Charcoal Made from Dairy Farming Waste as Bedding Material of Cattle, and Composting and Recycle Use as Fertilizer. *Bulletin of Chiba Prefectural Livestock Research Center*, **4**, 25-28.

[14] Hua, L., Wu, W., Liu, Y., McBride, M.B. and Chen, Y. (2009) Reduction of Nitrogen Loss and Cu and Zn Mobility during Sludge Composting with Bamboo Charcoal Amendment. *Environmental Science and Pollution Research*, **16**, 1-9. http://dx.doi.org/10.1007/s11356-008-0041-0

[15] Levine, J. (2010) Assessment of Biochar's Benefits for the United States of America. US Focused Biochar Report.

[16] Sonoki, T., Furukawa, T., Mizumoto, H., Jindo, K., Aoyama, M. and Monedero, M.Á.S. (2011) Impacts of Biochar Addition on Methane and Carbon Dioxide Emissions during Composting of Cattle Manure. *Asia Pacific Bioinformatics Conference*.

[17] Maeda, K., Hanajima, D., Morioka, R. and Osada, T. (2010) Characterization and Spatial Distribution of Bacterial Communities within Passively Aerated Cattle Manure Composting Piles. *Bioresource Technology*, **101**, 9631-9637. http://dx.doi.org/10.1016/j.biortech.2010.07.057

[18] Wu, W.X., Li, L.J., Lv, H.H., Wang, C., Deng, H. (2012) Mechanisms of Nitrous Oxide Emission during Livestock Manure Aerobic Composting. *Chinese Journal of Applied Ecology*, **23**, 1704-1712.

[19] Tsujimoto, Y., Masuda, J., Fukuyama, J. and Ito, H. (1994) N_2O Emissions at Solid Waste Disposal Sites in Osaka City. *Air and Waste*, **44**, 1313-1314. http://dx.doi.org/10.1080/10473289.1994.10467327

[20] Amlinger, F., Peyr, S. and Cuhls, C. (2008) Green House Gas Emissions from Composting and Mechanical Biological Treatment. *Waste Management and Research*, **26**, 47-60. http://dx.doi.org/10.1177/0734242X07088432

[21] Cabrera, M.L. and Chiang, S.C. (1994) Water Content Effect on Denitrification and Ammonia Volatilization in Poultry Litter. *Soil Science Society of America Journal*, **58**, 811-816. http://dx.doi.org/10.2136/sssaj1994.03615995005800030025x

[22] Brown, S., Kruger, C. and Subler, S. (2008) Greenhouse Gas Balance for Composting Operations. *Journal of Environmental Quality*, **37**, 1396-1410. http://dx.doi.org/10.2134/jeq2007.0453

[23] Osada, T., Kuroda, K. and Yonaga, M. (2000) Determination of Nitrous Oxide, Methane, and Ammonia Emissions from a Swine Waste Composting Process. *Journal of Material Cycles and Waste Management*, **2**, 51-56.

[24] Liang, C., Das, K.C. and McClendon, R.W. (2003) The Influence of Temperature and Moisture Contents Regimes on the Aerobic Microbial Activity of a Biosolids Composting Blend. *Bioresource Technology*, **86**, 131-137. http://dx.doi.org/10.1016/S0960-8524(02)00153-0

[25] Szanto, G.L., Hamelers, H.V.M., Rulkens, W.H. and Veeken, A.H.M. (2007) NH_3, N_2O and CH_4 Emissions during Passively Aerated Composting of Straw-Rich Pig Manure. *Bioresource Technology*, **98**, 2659-2670. http://dx.doi.org/10.1016/j.biortech.2006.09.021

[26] Tiquia, S.M., Tam, N.F.Y. and Hodgkiss, I.J. (1996) Microbial Activities during Composting of Spent Pig-Manure Sawdust Litter at Different Moisture Contents. *Bioresource Technology*, **55**, 201-206. http://dx.doi.org/10.1016/0960-8524(95)00195-6

[27] El Kader, N.A., Robin, P., Paillat, J.M. and Leterme, P. (2007) Turning, Compacting and the Addition of Water as Factors Affecting Gaseous Emissions in Farm Manure Composting. *Bioresource Technology*, **98**, 2619-2628. http://dx.doi.org/10.1016/j.biortech.2006.07.035

[28] Thompson, A.G., Wagner-Riddle, C. and Fleming, R. (2004) Emissions of N_2O and CH_4 during the Composting of Liquid Swine Manure. *Environmental Monitoring and Assessment*, **91**, 87-104. http://dx.doi.org/10.1023/B:EMAS.0000009231.04123.2d

[29] Fukumoto, Y., Osada, T., Hanajima, D. and Haga, K. (2003) Patterns and Quantities of NH_3, N_2O and CH_4 Emissions during Swine Manure Composting without Forced Aeration—Effect of Compost Pile Scale. *Bioresource Technology*,

89, 109-114. http://dx.doi.org/10.1016/S0960-8524(03)00060-9

[30] Imbeah, M. (1998) Composting Piggery Waste: A Review. *Bioresource Technology*, **63**, 197-203. http://dx.doi.org/10.1016/S0960-8524(97)00165-X

[31] Clough, T.J., Condron, L.M., Kammann, C. and Müller, C. (2013) A Review of Biochar and Soil Nitrogen Dynamics. *Agronomy*, **3**, 275-293. http://dx.doi.org/10.3390/agronomy3020275

[32] Liang, B., Lehmann, J., Solomon, D., Kinyangi, J., Grossman, J., O'Neill, B., *et al.* (2006) Black Carbon Increases Cation Exchange Capacity in Soils. *Soil Science Society of America Journal*, **70**, 1719-1730. http://dx.doi.org/10.2136/sssaj2005.0383

[33] Cheng, C.H., Lehmann, J. and Engelhard, M.H. (2008) Natural Oxidation of Black Carbon in Soils: Changes in Molecular Form and Surface Charge along a Climosequence. *Geochimica et Cosmochimica Acta*, **72**, 1598-1610.

[34] Chen, Y.X., Huang, X.D., Han, Z.Y., Huang, X., Hu, B., Shi, D.Z. and Wu, W.X. (2010) Effects of Bamboo Charcoal and Bamboo Vinegar on Nitrogen Conservation and Heavy Metals Immobility during Pig Manure Composting. *Chemosphere*, **78**, 1177-1181. http://dx.doi.org/10.1016/j.chemosphere.2009.12.029

[35] Dias, B.O., Silva, C.A., Higashikawa, F.S., Roig, A. and Sánchez-Monedero, M.A. (2010) Use of Biochar as Bulking Agent for the Composting of Poultry Manure: Effect on Organic Matter Degradation and Humification. *Bioresource Technology*, **101**, 1239-1246. http://dx.doi.org/10.1016/j.biortech.2009.09.024

[36] Haug, R.T. (1993) The Practical Handbook of Compost Engineering. CRC Press, Boca Raton.

[37] Adhikari, B.K., Barrington, S., Martinez, J. and King, S. (2009) Effectiveness of Three Bulking Agents for Food Waste Composting. *Waste Management*, **29**, 197-203. http://dx.doi.org/10.1016/j.wasman.2008.04.001

[38] Hamer, U., Marschner, B., Brodowski, S. and Amelung, W. (2004) Interactive Priming of Black Carbon and Glucose Mineralisation. *Organic Geochemistry*, **35**, 823-830. http://dx.doi.org/10.1016/j.orggeochem.2004.03.003

[39] Kuzyakov, Y., Subbotina, I., Chen, H., Bogomolova, I. and Xu, X. (2009) Black Carbon Decomposition and Incorporation into Soil Microbial Biomass Estimated by ^{14}C Labeling. *Soil Biology and Biochemistry*, **41**, 210-219. http://dx.doi.org/10.1016/j.soilbio.2008.10.016

[40] Prost, K., Borchard, N., Siemens, J., Kautz, T., Séquaris, J.M., Möller, A. and Amelung, W. (2013) Biochar Affected by Composting with Farmyard Manure. *Journal of Environmental Quality*, **42**, 164-172. http://dx.doi.org/10.2134/jeq2012.0064

[41] Jindo, K., Suto, K., Matsumoto, K., García, C., Sonoki, T. and Sanchez-Monedero, M.A. (2012) Chemical and Biochemical Characterisation of Biochar-Blended Composts Prepared from Poultry Manure. *Bioresource Technology*, **110**, 396-404. http://dx.doi.org/10.1016/j.biortech.2012.01.120