Gaseous Emissions from the Composting Process

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Compost can be used in agricultural activities due to its various positive impacts on the physical and chemical properties of the soil, meanwhile reducing utilization of inorganic fertilizers. Composting has also negative environmental impacts, some of them of social concern. This is the case of composting atmospheric emissions, especially in the case of greenhouse gases (GHG) and certain families of volatile organic compounds (VOC).

organic wastes composting gaseous emissions mitigation strategies

1. Introduction

As a result of increasing solid wastes' generation, the implementation of a reliable technology to deal with these wastes is considered as a pillar of sustainable development of any nation [1]. However, the selection of any technology should be compatible with the economic situation within the jurisdiction. Concurrently, the used technology has to satisfy the laws and regulations that fundamentally aim to reduce any environmental and health problems [2]. Among the different technologies used in this field is the composting process, which has been used to deal with solid wastes and mainly for the organic fraction of wastes [3][4]. This process is recognized as an environmentally friendly and cost-effective method, as organic matter is biologically degraded under aerobic conditions [5]. This biodegradation of organic matter contributes to reducing the volume of wastes and producing a stabilized and nutrient-rich final end product, "compost", that could be used in agricultural activities due to its various positive impacts on the physical and chemical properties of the soil, meanwhile reducing utilization of inorganic fertilizers [6][7][8]. Actually, when the process-controlling parameters are well adjusted, this will lead to different advantages; thereby the process is viewed as a sustainable alternative for landfilling and other treatment options [9]. However, even though composting is a natural biochemical decomposition process, a successful composting operation that produces a valuable end product is normally associated with releasing gaseous emissions including greenhouse gases (GHGs) into the atmosphere (**Figure 1**). The released GHGs are attributed to energy requirements for composting plants' operation and to the biochemical reactions within the organic waste itself, which produces CO_2, methane (CH_4), and nitrous oxide (N_2O) due to the mineralization and degradation of organic matters [10][11]. According to Hao et al. [12], the majority of organic carbon is converted to CO_2, whereas the methane accounts for less than 6%. Nevertheless, it should be noted that even though CO_2 represents the major part of the emissions, it does not add to global warming due to the biogenic origin of carbon. On the contrary, the other emissions resulting from the process such as CH_4 and N_2O have a direct impact on the global warming, while

NH_3, Sulphur compounds, and most of the volatile organic compounds (VOCs) emissions cause undesirable and other odor nuisances [9][13][14].

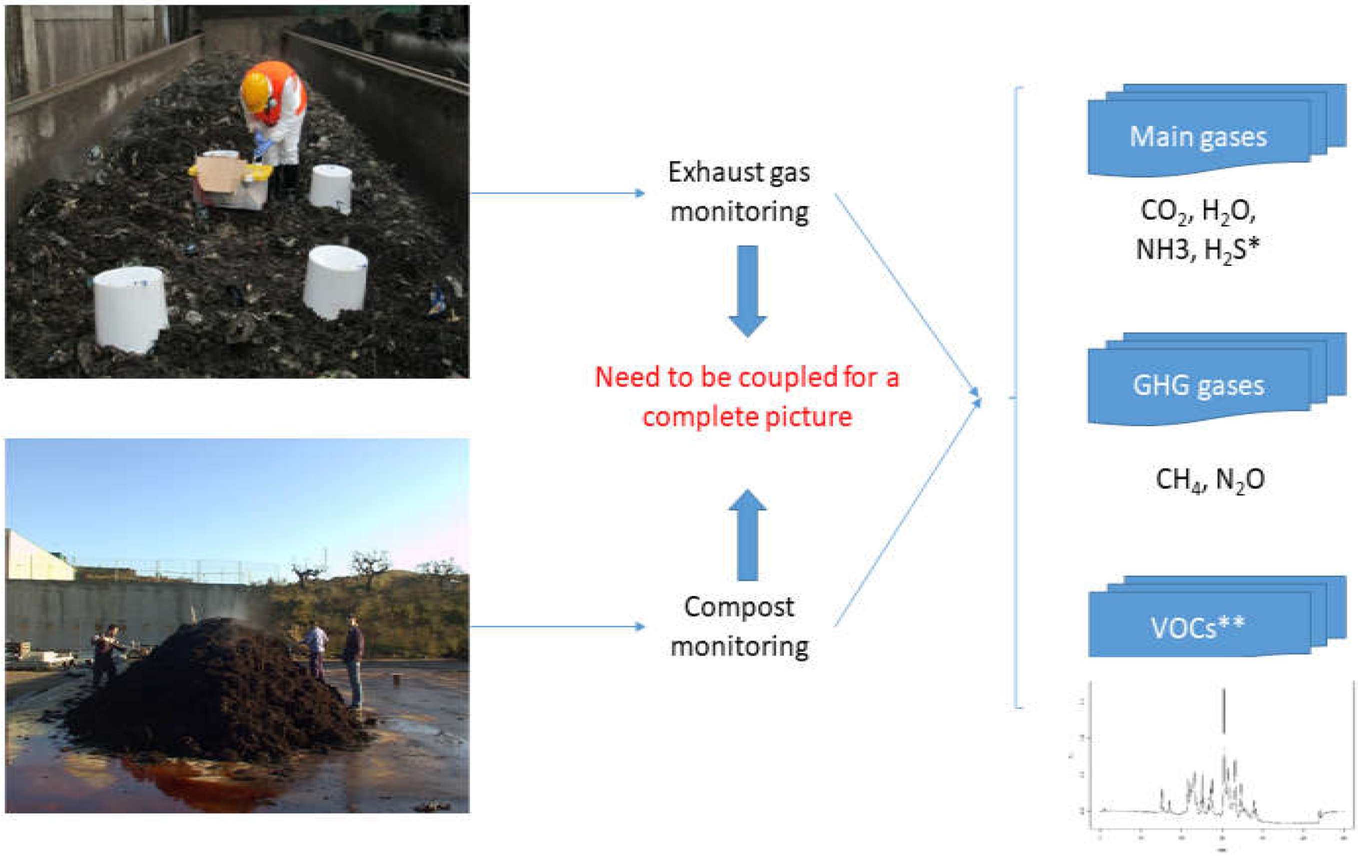

Figure 1. Monitoring exhaust gases from a composting process. * H_2S is only significantly observed when anaerobic conditions prevail in the composting process. ** VOCs: Volatile Organic Compounds, a wide group including families such as alcohols, aldehydes, alkanes, aromatic hydrocarbons, carboxylic acids, ketones, nitrogen compounds, phenols, sulphur compounds, and terpenes, among others.

2. Gas Emissions from Composting Process

As a result of microbial activities and putrefaction, gaseous emissions from organic wastes are produced [10]. These emissions, which include CO_2, CH_4, N_2O, Sulphur compounds, and many other volatile organic compounds (VOCs), as shown in **Table 1**, have been detected during the different phases of the waste management [9][15].

Table 1. Volatile organic compounds (VOCs) detected in the composting of different organic wastes.

Waste	Main VOC Family	Other VOCs	Reference
Poultry litter	Alkanes and alkylated benzenes	Aldehydes, terpenes, and ketones	[16]

Waste	Main VOC Family	Other VOCs	Reference
Chicken manure and biochar	Ketones, phenols, and organic acids	Aliphatic, aromatic, and terpenes	[17]
Municipal solid waste	Alkylated benzenes, alcohols, and alkanes	-	[14]
Wastewater sludge	Terpenes	Furans and esters	[18]
Digested wastewater sludge	Terpenes	Alcohols and Ketones	[18]
Swine carcass	Sulphur compounds	-	[19]
Municipal solid waste	Terpenes	Alcohols, volatile fatty acids, and aromatic compounds	[20]
Livestock and Poultry Manure	Sulfur compounds, aliphatic hydrocarbons, aromatic hydrocarbons	Chlorinated organic compounds	[21]
Municipal solid waste digestate	Terpenes and oxygenated compounds	Sulphur compounds and methanethiol	[22]
Green waste	Alcohols	Alkenes, aliphatic alkanes, aromatic hydrocarbons, ketones, aldehydes, furans, and esters	[23]
Sewage sludge	Isovaleraldehyde, butyric acid, sulphur compounds, and pinene	Indole, skatole, and phenol	[24]

During the initial stages of the composting process, both nitrogen and sulfur are in the organic form [25]. As the process proceeds forward, the mineralization of the organic nitrogen leads to the formation of ammonia (NH_3), which could react with hydrogen ions to form ammonium (NH_4^+). The NH_4^+-to-NH_3 equilibrium is highly affected by the dominant conditions within the composting mixture, mainly the pH value and temperature [26][27][28]. Thermophilic temperatures and alkaline conditions enhance the loss of nitrogen as ammonia. Additionally, ammonia-oxidizing bacteria or archaea and nitrite-oxidizing bacteria convert part of the nitrogen to nitrate through the nitrification process. This nitrate is used by the microbial community, but it would be converted to N_2O under certain conditions including denitrifications' process, especially under insufficient oxygen levels [26]. Furthermore, the low levels of oxygen lead to the formation of some anaerobic zones within the compositing mixture. These zones play a major role in the sulfur transformation and the production of H_2S through the action of Sulfate-reducing bacteria (anaerobic) during the degradation of the organic matter [29]. Additionally, during the formation of H_2S, other reduced sulfur compounds will also be produced, such as MeSH, Me2S, Me2SS, and others [26].

4. Mitigation Strategies

4.1. Providing Adequate Bulking Agent

The addition of some materials to organic wastes has proven its efficiency in improving air convection within the composting mixture, thereby reducing the amount of gases' emissions such as CH_4 and N_2O from composting, since most of the degraded carbon would be released as CO_2 [11][30][31]. For instance, sawdust and straw for dairy manure composting resulted in an effective mitigation for CH_4 and NH_3 with ME values of 66.3% and 44.0%, but they may increase CO_2 emission [12][32]. Additionally, Li et al. [33] demonstrated that ammonia emission may well be mitigated by adding a mix of sucrose and straw powder at the start stage of a composting process [34]. Indeed, these materials facilitate the absorption and microbial assimilation of ammonium, which decreases NH_3 emissions [9][35][34].

4.2. Introducing Microorganism for Promoting Nitrification Process and Reducing NH_3 Emissions

This approach stands on the mineralization of organic nitrogen into ammonium nitrogen, which could be transformed into nitrate by nitrification and eventually to N_2 by denitrification, or the ammonium could even be also a fixed microbial protein under the action of fungi [35][31][36][37][38][39]. It was found that the introduction of mature compost rich in nitrifying microorganism to food wastes' composting was able to reduce NH_3 volatilization by 36% [40]. Nevertheless, and despite the capability of this approach in reducing NH_3 emission, regulating the denitrification process to reduce N_2 and N_2O still represents a challenge for its successful application [5][39]. Additionally, the introduction of some exogenous microbial communities including CC-E (a complex bacterial community in which *Alcaligenes faecalis* is the main advantageous strain) and EM (Effective Microorganisms, a kind of commercial microbiological agent) for dairy manure composting reduced the potential for NH_3 emissions, with ME of 9.15% [40][41].

4.3. Vermicomposting

This composting approach demonstrated promising results in reducing the amounts of gaseous emissions including nitrous oxide, CH_4, NH_3, and others [34][42]. The decrease in emissions' rates is attributed to the reduction of anaerobic denitrification, due to the burrowing action of the earthworms [43]. Furthermore, the large specific surface area and loose texture in vermicomposting contribute to creating a strong adsorption capacity and, at last, reducing production of different emissions, among them the NH_3, where vermicomposting was able to mitigate NH_3 emission with a ME median value of 33.5% [44][35][45]. The loss of texture improves the aerobic conditions and,, therefore, the biodegradation of the organic matter as a consequence. In this regard, it was noticed that CO_2 emissions were increased, whereas a decrease in ammonia emissions and nitrous oxide was noticed as well as a sink of methane in treatments with earthworms [46][47]. Similar results were obtained by Chan et al. [45] and Velasco-Velasco et al. [48]. Combining pre-composting and vermicomposting with additions of reed straw and zeolite resulted also in a significant reduction of ammonia, nitrous oxide, and methane during composting of duck manure [34][48].

4.4. Using Different Additives

The addition of phosphogypsum results in decreasing the pH of the composting mixture. The high sulphide concentrations and acidic conditions due to the use of phosphogypsum could inhibit methanogenesis and the action of N_2O reductase, thus reducing CH_4 and N_2O emissions [12][35][49][50]. Additionally, adjustment of pH has been practiced to reduce the emissions of NH_3. About 55.7% of NH_3 emissions was decreased due to the reduction in volatilization when phosphogypsum was applied [51]. Additionally, the addition of both $K_2HPO_4/MgSO_4$ and $KH_2PO_4/MgSO_4$ as a pH buffer agent's additive contributed to reducing NH_3 emissions [36]. However, health risks due to high hydrogen sulphide concentrations have to be considered when this mitigation method is to be used [35][52]. Manure acidification significantly (up to 93%) decreased the emissions during storage and composting processes [53][54]. Excessive acidification (pH = 5), on the other hand, increased N_2O emissions (18.6%) during composting. When manure was acidified to pH of 6, N_2O (17.6%) and CH_4 (20%) emissions, as well as GHG emissions, represented as global warming potential (GWP) (9.6%) were reduced during composting [55]. The addition of calcium magnesium phosphate fertilizer (CaMgP) also demonstrated its effectiveness in reducing emissions' rates during the composting process [56]. In this regard, Zhang et al. [57] reported that CaMgP could reduce H_2S emissions by 65%. Similar results were obtained when the effect of calcium magnesium phosphate fertilizer (CaMgP), biochar, and spent mushroom substrate (SMS) additives was investigated on compost maturity and gaseous emissions during pig manure composting. Ammonia (NH_3), hydrogen sulfide (H_2S), dimethyl sulfide (Me_2S), and dimethyl disulfide (Me_2SS) emissions could all be reduced using the three additives. However, when it came to reducing NH_3 emissions, the effect of adding CaMgP was the most noticeable (42.90%). CaMgP to H_2S emission reduction was similar to SMS, which was 34.91% and 32.88%, respectively. The three additives had obvious emission reduction effects on Me_2S and Me_2SS, all of which were greater than 50%. Adding SMS, on the other hand, reduced N_2O emissions by 37.08% [58].

Struvite could also be used to reduce emissions as struvite crystallization enhances nitrogen (ammonium) conservation during composting, which thereby reduces NH_3 emissions [59][60]. However, this approach increases the salinity of the produced compost [5][33], but this limitation could be mitigated by using other additives like lime or zeolite [61][62]. In this regard, the addition of 10% of zeolite decreased the salinity to 2.8 mS cm^{-1} and improved compost maturity; meanwhile, about 18% of NH_3 loss was achieved [62].

4.5. Compressing and Covering

This approach depends on reducing the amount of O_2 supplied to the mixture, thus lowering the microbial activity and ammonization, which reduce CO_2 and NH_3 emissions during the composting process [37][63]. Additionally, covering reduces gaseous diffusion into the air and enhances the absorption of some gas emissions. Analysis revealed that this approach could reach a mitigation efficiency of 10.1% for CO_2 and 24.3% for NH_3 emission. However, it should be noted that this approach would increase the anaerobic conditions that ultimately promote the production of CH_4 [44][35][43][46]. Different materials are used as a cover for composting mixture. These materials include sawdust, plastic, soil, paper waste, woodchip, wheat straw, peat, and zeolite, among others. Sawdust or straw has a good performance in absorption of CO_2 and NH_3, whereas plastic cover renders the gas exchange, which reduces the dissipation of the emissions [44][35][46][64][65]. Different forms of zeolite were used as a cover or even mixed with the composting mixture and proved higher efficiency in reducing emission compared to other cover materials with almost no effect on the microbial activity [5][57][40][66][67]. This material contributes to increasing the pH and initial NH_3/NH_4^+ concentration, which reduces NH_3 losses such that a reduction of 44–60% of the NH_3 was obtained during poultry manure composting [68]. Similar results were observed by Madrini et al. [66] in composting of leftover food. It should be noted that the type of zeolite and its percentage within the mixture affects the reduction rate of emissions [5][67].

4.6. Biofiltration

Biofilters, which depend on adsorption or biodegradation of pollutants, have proven their relative efficiency in reducing emissions from the composting process, especially with NH_3, where almost about 90% of this gas was reduced [35][69]. Actually, ammonia emissions in a composting process of organic fraction of municipal solid wastes varied between 18 to 150 g $NH_3 \cdot Mg^{-1}$ waste [70], while ammonia concentrations up to 700 mg $NH_3 \cdot m^{-3}$ have been reported in exhaust gases from sludge composting [4]. As documented by Pagans et al. [71], the biofilter achieved a global ammonia removal efficiency of 95.9% at a loading rate range of 846–67100 mg $NH_3 \cdot m^{-3}$ biofilter$\cdot h^{-1}$, whereas higher removal rates were seen when the waste gas had high NH_3 concentrations (more than 2000 mg $NH_3 \cdot m^{-3}$). However, this approach is more feasible compared to other technologies when it is used in closed systems with collection equipment [44]. Furthermore, the complexity and uncertainty measures in operating the system, as well as understanding the biodegradation process, are critical for optimal performance. [9]. Concerning CH_4, CO_2, and N_2O emissions, the literature is lacking information about the efficiency of biofilter for treatment of these emissions [35].

4.7. Addition of Biochar

Biochar as an additive has been used in different research to mitigate the emissions resulting from composting processes [33][36][58][72][73]. This additive has been used as a sole material or mixed with other additives [74]. Noteworthy, under almost all studied conditions, promising results were obtained, despite the lack of clarity regarding its mechanism on promoting nitrogen assimilation and nitrification [5][31][38][75]. The change in nitrogen functional groups on the biochar surface was evidence for adsorption and microbial transformation of NH_3/NH_4^+ [76]. As indicated in several works, the biochar promoted microbial activity during the composting process, as it increases the nitrogen source and decreases toxicity of free NH_3 on the microbial activity [77]; hence, a high respiration rate as well as a fast decomposition of organic matter were recorded [75][77][78]. Additionally, this was associated with an increase in the temperature and NO_3 concentration along with a decrease in the pH and NH_4^+ concentrations [71][73]. Emissions of NH_3 and nitrogen losses were reduced by 64% and 52%, respectively, when biochar was mixed with poultry litters [37]. Similar results were observed when cornstalk biochar was used where cumulative NH_3 emissions were reduced by 24.8% [79]. The presence of the biochar boosted the activity of nitrifiers due to its high sorption capacity for gases and the high cation exchange capacity. According to Zhou et al. [80], adding modified biochar could significantly reduce NH_3 emissions by increasing the number of ammonia-oxidizing bacteria (AOB), inhibiting urease activity, and decreasing the abundance of nitrogen functional genes such as narG and nirS, facilitating the conversion of $NH^+{}_4$-N into $NO^-{}_3$-N and decreasing nitrogen loss. These conditions were responsible for promoting N_2O reduction up to 59.8% [81]. The effects of bamboo charcoal (BC) and bamboo vinegar (BV) on lowering NH_3 and N_2O emissions during aerobic composting (Wheat straw and pig manure) revealed that both BC and BV enhanced nitrogen conversion and compost quality, with the combination BC + BV treatment achieving the greatest results. The BC, BV, and BC + BV treatments decreased NH_3 emissions by 14.35%, 17.90%, and 29.83%, respectively, and the N_2O emissions by 44.83%, 55.96%, and 74.53%. BC and BV reduced the NH_3 and N_2O emissions during composting [82]. Similarly, Biochar (BC) and bean dregs' (BD) effects on nitrifiers and denitrifiers, as well as contributions to NH_3 and N_2O emissions, were investigated by Yang et al. [83]. When comparing the BD + BC treatment to the BD treatment, the highest value of NH_3 and N_2O emission was reduced by 32.92% and 46.61%, respectively. The number and structure of nitrogen functional genes were shown to be closely related to the synthesis of NH_3 and N_2O in the study. In this case, it was discovered that BD + BC enhanced the abundance of the AOB amoA gene, resulting in a reduction in NH_3 emission. The presence of nirS was more closely linked to the presence of N_2O. When compared to the BD treatment, the abundance of nirS in the BD + BC treatment was reduced by 18.93%, lowering N_2O emissions after composting. Furthermore, the nosZ-type gene was the most functional denitrification bacterial community to influence N_2O emissions. [83]. Noteworthy, when biochar is to be used, it is important to keep in mind that its characteristics have a major role on its efficiency.

5. Conclusions

Composting is a favorable technology to treat organic waste, but gaseous emissions are an issue of major concern for its development. Among them, GHG emissions are an important problem as they are responsible for the global warming effect. Carbon dioxide is not often considered, as it is considered biogenic. However, methane and nitrous oxide, related to anaerobic and anoxic conditions, must be accounted for when analyzing any composting process. Another important point is the release in the form of gaseous emissions of a vast family of compounds such as VOCs. These gases can be harmful, possess negative impacts, and, especially, are responsible for unpleasant odors. The origin of these gases is double (they can come from the substrate or be biologically or even chemically formed during the process) and they need the development of mitigation strategies based on relatively consolidated technologies (such as biofiltration) or new approaches, such as the use of materials as biochar. However, there is still a lack of reliable and full-scale data from composting emissions to have consistent mitigation strategies.

References

1. Iqbal, A.; Liu, X.; Chen, G. Municipal solid waste: Review of best practices in application of life cycle assessment and sus-tainable management techniques. Sci. Total Environ. 2020, 729, 138622.
2. Kaza, S.; Yao, L.; Bhada-Tata, P.; Van Woerden, F. What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050; Urban Development Series; World Bank Publications: Washington, DC, USA, 2018.
3. Bogner, J.; Pipatti, R.; Hashimoto, R.; Diaz, C.; Mareckova, K.; Diaz, L.; Kjeldsen, P.S.; Faaij, A.; Gao, Q.; Zhang, T.; et al. Mitigation of global GHG emissions from waste: Conclusions and strategies from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. Working Group III (Mitigation). Waste Manag. Res. 2008, 26, 11–13.
4. Haug, R. The Practical Handbook of Compost Engineering; Lewis Publishers: Boca Raton, FL, USA, 1993.
5. Wang, S.; Zeng, Y. Ammonia emission mitigation in food waste composting: A review. Bioresour. Technol. 2018, 248, 13–19.
6. Hodge, K.L.; Levis, J.W.; Decarolis, J.F.; Barlaz, M.A. Systematic Evaluation of Industrial, Commercial, and Institutional Food Waste Management Strategies in the United States. Environ. Sci. Technol. 2016, 50, 8444–8452.
7. Sayara, T.; Basheer-Salimia, R.; Hawamde, F.; Sanchez, A. Recycling of Organic Wastes through Composting: Process Per-formance and Compost Application in Agriculture. Agronomy 2020, 10, 1838.
8. Varma, V.S.; Kalamdhad, A.S. Stability and microbial community analysis during rotary drum composting of vegetable waste. Int. J. Recycl. Org. Waste Agric. 2014, 3, 52.
9. Dhamodharan, K.; Varma, V.S.; Veluchamy, C.; Pugazhendhi, A.; Rajendran, K. Emission of volatile organic compounds from composting: A review on assessment, treatment and perspectives. Sci. Total. Environ. 2019, 695, 133725.
10. Friedrich, E.; Trois, C. GHG emission factors developed for the recycling and composting of municipal waste in South African municipalities. Waste Manag. 2013, 33, 2520–2531.

11. Luo, W.; Yuan, J.; Luo, Y.M.; Li, G.X.; Nghiem, L.; Price, W.E. Effects of mixing and covering with mature compost on gaseous emissions during composting. Chemosphere 2014, 117, 14–19.
12. Hao, X.; Chang, C.; Larney, F.J. Carbon, nitrogen balances and greenhouse gas emission during cattle feedlot manure composting. J. Environ. Qual. 2004, 33, 37–44.
13. Colón, J.; Cadena, E.; Pognani, M.; Barrena, R.; Sánchez, A.; Font, X.; Artola, A. Determination of the energy and environ-mental burdens associated with the biological treatment of source-separated municipal solid wastes. Energy Environ. Sci. 2012, 5, 5731–5741.
14. Komilis, D.P.; Ham, R.K.; Park, J.K. Emission of volatile organic compounds during composting of municipal solid wastes. Water Res. 2004, 38, 1707–1714.
15. Sánchez, A.; Artola, A.; Font, X.; Gea, T.; Barrena, R.; Gabriel, D.; Sanchez-Monedero, M.; Roig, A.; Cayuela, M.L.; Mondini, C. Greenhouse gas emissions from organic waste composting. Environ. Chem. Lett. 2015, 13, 223–238.
16. Turan, N.G.; Akdemir, A.; Ergun, O.N. Emission of Volatile Organic Compounds during Composting of Poultry Litter. Water, Air, Soil Pollut. 2007, 184, 177–182.
17. Sánchez-Monedero, M.A.; Sánchez-García, M.; Alburquerque, J.A.; Cayuela, M.L. Biochar reduces volatile organic com-pounds generated during chicken manure composting. Bioresour Technol. 2019, 288, 121584.
18. Maulini-Duran, C.; Artola, A.; Font, X.; Sánchez, A. A systematic study of the gaseous emissions from biosolids composting: Raw sludge versus anaerobically digested sludge. Bioresour. Technol. 2013, 147, 43–51.
19. Akdeniz, N.; Koziel, J.A.; Ahn, H.K.; Glanville, T.D.; Crawford, B.P.; Raman, D.R. Laboratory scale evaluation of volatile organic compound emissions as indication of swine carcass degradation inside biosecure composting units. Bioresour. Technol. 2010, 101, 71–78.
20. Sánchez-Monedero, M.A.; Fernández-Hernández, A.; Higashikawa, F.S.; Cayuela, M.L. Relationships between emitted volatile organic compounds and their concentration in the pile during municipal solid waste composting. Waste Manag. 2018, 79, 179–187.
21. Wang, Y.-J.; Xing, Z.-X.; Zhang, X.-F.; Hou, Z.-G.; Zhao, X.-S.; Dou, S.; Zhou, M.-P. On-site Detection of Volatile Organic Compounds During Composting Treatment of Livestock and Poultry Manure by GC-MS. Chin. J. Anal. Chem. 2013, 40, 899–903.
22. Rincón, C.A.; De Guardia, A.; Couvert, A.; Le Roux, S.; Soutrel, I.; Daumoin, M.; Benoist, J.C. Chemical and odor charac-terization of gas emissions released during composting of solid wastes and digestates. J. Environ. Manag. 2019, 233, 39–53.
23. Kumar, A.; Alaimo, C.P.; Horowitz, R.; Mitloehner, F.M.; Kleeman, M.J.; Green, P.G. Volatile organic compound emissions from green waste composting: Characterization and ozone

formation. Atmos. Environ. 2011, 45, 1841–1848.

24. González, D.; Colón, J.; Sánchez, A.; Gabriel, D. A systematic study on the VOCs characterization and odour emissions in a full-scale sewage sludge composting plant. J. Hazard. Mater. 2019, 373, 733–740.
25. Bohacz, J. Changes in mineral forms of nitrogen and sulfur and enzymatic activities during composting of lignocellulosic waste and chicken feathers. Environ. Sci. Pollut. Res. 2019, 26, 10333–10342.
26. Zhu, P.; Shen, Y.; Pan, X.; Dong, B.; Zhou, J.; Zhang, W.; Li, X. Reducing odor emissions from feces aerobic composting: Additives. RSC Adv. 2021, 11, 15977–15988.
27. Liang, Y.; Leonard, J.J.; Feddes, J.J.; McGill, W.B. A SIMULATION MODEL OF AMMONIA VOLATILIZATION IN COMPOSTING. Trans. ASAE 2004, 47, 1667–1680.
28. Wang, Y.; Liu, S.J.; Xue, W.T.; Guo, H.; Li, X.R.; Zuo, G.Y.; Zhao, T.K.; Dong, H.M. The Characteristics of Carbon, Ni-trogen and Sulfur Transformation During Cattle Manure Composting-Based on Different Aeration Strategies. Int. J. Environ. Res. Public Health. 2019, 16, 3930.
29. Chen, J.; Chen, T.-B.; Gao, D.; Lei, M.; Zheng, G.-D.; Liu, H.-T.; Guo, S.-L.; Cai, L. Reducing H2S production by O2 feedback control during large-scale sewage sludge composting. Waste Manag. 2011, 31, 65–70.
30. Maeda, K.; Hanajima, D.; Morioka, R.; Toyoda, S.; Yoshida, N.; Osada, T. Mitigation of greenhouse gas emission from the cattle manure composting process by use of a bulking agent. Soil Sci. Plant. Nutr. 2013, 59, 96–106.
31. Chowdhury, M.A.; de Neergaard, A.; Jensen, L.S. Potential of aeration flow rate and bio-char addition to reduce greenhouse gas and ammonia emissions during manure composting. Chemosphere 2014, 97, 16–25.
32. Barrington, S.; Choinière, D.; Trigui, M.; Knight, W. Compost convective airflow under passive aeration. Bioresour. Technol. 2003, 86, 259–266.
33. Wang, X.; Selvam, A.; Chan, M.; Wong, J.W.C. Nitrogen conservation and acidity control during food wastes com-posting through struvite formation. Bioresour. Technol. 2013, 147, 17–22.
34. Lim, S.L.; Lee, L.H.; Wu, T.Y. Sustainability of using composting and vermicomposting technologies for organic solid waste biotransformation: Recent overview, greenhouse gases emissions and economic analysis. J. Clean. Prod. 2016, 111, 262–278.
35. Ba, S.; Qu, Q.; Zhang, K.; Groot, J.C.J. Meta-analysis of greenhouse gas and ammonia emissions from dairy manure com-posting. Biosyst. Eng. 2020, 193, 126–137.

36. Li, S.; Huang, G.-H.; An, C.-J.; Yu, H. Effect of different buffer agents on in-vessel composting of food waste: Performance analysis and comparative study. J. Environ. Sci. Heal. Part. A 2013, 48, 772–780.
37. Chadwick, D.R. Emissions of ammonia, nitrous oxide and methane from cattle manure heaps: Effect of compaction and covering. Atmos. Environ. 2005, 39, 787–799.
38. Chowdhury, M.A.; de Neergaard, A.; Jensen, L.S. Composting of solids separated from anaerobically digested animal manure: Effect of different bulking agents and mixing ratios on emissions of greenhouse gases and ammonia. Biosys. Eng. 2014, 124, 63–77.
39. Steiner, C.; Das, K.C.; Melear, N.; Lakly, D. Reducing Nitrogen Loss during Poultry Litter Composting Using Biochar. J. Environ. Qual. 2010, 39, 1236–1242.
40. Al-Jabi, L.F.; Halalsheh, M.M.; Badarneh, D.M. Conservation of ammonia during food waste composting. Environ. Technol. 2008, 29, 1067–1073.
41. Zeng, Y.; De Guardia, A.; Dabert, P. Imporve composting as a post-treatment of anaerobic digestate. Bioresour. Technol. 2016, 201, 293–303.
42. Chen, W.; Yan, L.; Gao, Y.; Bao, J.; Wang, Y.; Sun, Z.; Wang, W. The removal characteristics and diversity of a microbial community capable of ammonia removal from compost. Ann. Microbiol. 2016, 66, 635–642.
43. Shan, J.; Shao, X. Nitrogen preserving and deodorizing technology in high temperature composting of cow manure. Environ. Sci. Technol. 2008, 31, 47–50.
44. Wang, Y.; Li, X.; Yang, J.; Tian, Z.; Sun, Q.; Xue, W.; Dong, H. Mitigating Greenhouse Gas and Ammonia Emissions from Beef Cattle Feedlot Production: A System Meta-Analysis. Environ. Sci. Technol. 2018, 52, 11232–11242.
45. Chan, Y.C.; Sinha, R.K.; Wang, W.J. Emission of greenhouse gases from home aerobic composting, anaerobic digestion and vermicomposting of household wastes in Brisbane (Australia). Waste Manag. Res. 2010, 29, 540–548.
46. Chen, R.; Wang, Y.; Wang, W.; Wei, S.; Jing, Z.; Lin, X. N2O emissions and nitrogen transformation during windrow com-posting of dairy manure. J. Environ. Manag. 2015, 160, 121–127.
47. Robin, P.; Germain, P.; Lecomte, M.; Landrain, B.; Li, Y.; Cluzeau, D. Earthworm effects on gaseous emissions during vermifiltration of pig fresh slurry. Bioresour. Technol. 2011, 102, 3679–3686.
48. Velasco-Velasco, J.; Parkinson, R.; Kuri, V. Ammonia emissions during vermicomposting of sheep manure. Bioresour. Technol. 2011, 102, 10959–10964.

49. Wang, J.; Hu, Z.; Xu, X.; Jiang, X.; Zheng, B.; Liu, X.; Pan, X.; Kardol, P. Emissions of ammonia and greenhouse gases during combined pre-composting and vermicomposting of duck manure. Waste Manag. 2014, 34, 1546–1552.

50. Liu, B.; Mørkved, P.T.; Frostegård, A.; Bakken, L.R. Denitrification gene pools, transcription and kinetics of NO, N2O and N2 production as affected by soil pH. FEMS Microbiol. Ecol. 2010, 72, 407–417.

51. Tubail, K.; Chen, L.; Michel, F.C., Jr.; Keener, H.M.; Rigot, J.F.; Klingman, M.; Kost, D.; Dick, W.A. Gypsum additions reduce ammonia nitrogen losses during composting of dairy manure and biosolids. Compost Sci. Util. 2008, 16, 285–293.

52. Wang, Q.; Wang, Z.; Awasthi, M.K.; Jiang, Y.; Li, R.; Ren, X.; Zhao, J.; Shen, F.; Wang, M.; Zhang, Z. Evaluation of medical stone amendment for the reduction of nitrogen loss and bioavailability of heavy metals during pig manure composting. Bioresour. Technol. 2016, 220, 297–304.

53. Hou, Y.; Velthof, G.L.; Oenema, O. Mitigation of ammonia, nitrous oxide and methane emissions from manure management chains: A meta-analysis and integrated assessment. Glob. Chang. Biol. 2015, 21, 1293–1312.

54. Ti, C.; Xia, L.; Chang, S.X.; Yan, X. Potential for mitigating global agricultural ammonia emission: A meta-analysis. Environ. Pollut. 2019, 245, 141–148.

55. Cao, Y.; Wang, X.; Liu, L.; Velthof, G.L.; Misselbrook, T.; Bai, Z.; Ma, L. Acidification of manure reduces gaseous emissions and nutrient losses from subsequent composting process. J. Environ. Manag. 2020, 264, 110454.

56. Li, Y.; Luo, W.; Li, G.; Wang, K.; Gong, X. Performance of phosphogypsum and calcium magnesium phosphate fertilizer for nitrogen conservation in pig manure composting. Bioresour. Technol. 2018, 250, 53–59.

57. Zhang, J.; Sui, Q.; Li, K.; Chen, M.; Tong, J.; Qi, L.; Wei, Y. Influence of natural zeolite and nitrification inhibitor on organics degradation and nitrogen transformation during sludge composting. Environ. Sci. Pollut. Res. 2017, 24, 9122.

58. Liu, Y.; Ma, R.; Li, D.; Qi, C.; Han, L.; Chen, M.; Fu, F.; Yuan, J.; Li, G. Effects of calcium magnesium phosphate fertilizer, biochar and spent mushroom substrate on compost maturity and gaseous emissions during pig manure composting. J. Environ. Manag. 2020, 267, 110649.

59. Yuan, J.; Chadwick, D.; Zhang, D.; Li, G.; Chen, S.; Luo, W.; Du, L.; He, S.; Peng, S. Effects of aeration rate on maturity and gaseous emissions during sewage sludge composting. Waste Manag. 2016, 56, 403–410.

60. Jiang, T.; Ma, X.; Tang, Q.; Yang, J.; Li, G.; Schuchardt, F. Combined use of nitrification inhibitor and struvite crystallization to reduce the NH3 and N2O emissions during composting. Bioresour. Technol. 2016, 217, 210–218.

61. Wang, X.; Selvam, A.; Wong, J.W. Influence of lime on struvite formation and nitrogen conservation during food waste composting. Bioresour. Technol. 2016, 217, 227–232.
62. Chan, M.T.; Selvam, A.; Wong, J.W. Reducing nitrogen loss and salinity during 'struvite' food waste composting by zeolite amendment. Bioresour. Technol. 2016, 200, 838–844.
63. Jungbluth, T.; Hartung, E.; Brose, G. Greenhouse gas emissions from animal houses and manure stores. Nutr. Cycl. Agroecosystems 2001, 60, 133–145.
64. Huang, G.; Fang, C.; Ma, S.; Han, L. Storage stability of micro-aerobic coupling functional membrane and gas emission reduction of dairy manure. Trans. Chin. Soc. Agric. Mach. 2018, 49, 335–341.
65. Zhu, X.; Dong, W.; Wang, H.; Yan, C.; Liu, H.; Liu, E. Effects of cattle manure composting methods on greenhouse gas and ammonia emissions. Trans. Chin. Soc. Agric. Eng. 2017, 33, 258–264.
66. Madrini, B.; Shibusawa, S.; Kojima, Y.; Hosaka, S. Effect of natural zeolite (clinoptilolite) on ammonia emissions of leftover food-rice hulls composting at the initial stage of the thermophilic process. J. Agric. Meteorol. 2016, 72, 12–19.
67. Villaseñor, J.; Rodríguez, L.; Fernández, F.J. Composting domestic sewage sludge with natural zeolites in a rotary drum reactor. Bioresour. Technol. 2011, 102, 1447–1454.
68. Turan, N.G. Nitrogen availability in composted poultry litter using natural amendments. Waste Manag. Res. 2009, 27, 19–24.
69. Hong, J.H.; Park, K.J. Compost biofiltration of ammonia gas from bin composting. Bioresour. Technol. 2005, 96, 741–745.
70. Clemens, J.; Cuhls, C. Greenhouse gas emissions from mechanical and biological waste treatment of municipal waste. Environ. Technol. 2003, 24, 745–754.
71. Pagans, E.; Font, X.; Sánchez, A. Biofiltration for ammonia removal from composting exhaust gases. Chem. Eng. J. 2005, 113, 105–110.
72. Li, Q.; Wang, X.C.; Zhang, H.H.; Shi, H.L.; Hu, T.; Ngo, H.H. Characteristics of nitrogen transformation and microbial community in an aerobic composting reactor under two typical temperatures. Bioresour. Technol. 2013, 137, 270–277.
73. Liu, W.; Huo, R.; Xu, J.; Liang, S.; Li, J.; Zhao, T.; Wang, S. Effects of biochar on nitrogen transformation and heavy metals in sludge composting. Bioresour. Technol. 2017, 235, 43–49.
74. Awasthi, M.K.; Wang, Q.; Huang, H.; Li, R.; Shen, F.; Lahori, A.H.; Wang, P.; Guo, D.; Guo, Z.; Jiang, S.; et al. Effect of biochar amendment on greenhouse gas emission and bio-availability of heavy metals during sewage sludge co-composting. J. Clean. Prod. 2016, 135, 829–835.

75. Malińska, K.; Zabochnicka-Świątek, M.; Dach, J. Effects of biochar amendment on ammonia emission during composting of sewage sludge. Ecol. Eng. 2014, 71, 474–478.
76. Agyarko-Mintah, E.; Cowie, A. Biochar increases nitrogen retention and lowers greenhouse gas emissions when added to composting poultry litter. Waste Manag. 2017, 61, 138–149.
77. Sun, D.; Lan, Y.; Xu, E.G.; Meng, J.; Chen, W. Biochar as a novel niche for culturing microbial communities in composting. Waste Manag. 2016, 54, 93–100.
78. Khan, N.; Clark, I.; Sánchez-Monedero, M.A.; Shea, S.; Meier, S.; Bolan, N. Maturity indices in co-composting of chicken manure and sawdust with biochar. Bioresour. Technol. 2014, 168, 245–251.
79. Chen, W.; Liao, X.; Wu, Y.; Liang, J.B.; Mi, J.; Huang, J.; Zhang, H.; Wu, Y.; Qiao, Z.; Li, X.; et al. Effects of different types of biochar on methane and ammonia mitigation during layer manure composting. Waste Manag. 2017, 61, 506–515.
80. Zhou, S.; Wen, X.; Cao, Z.; Cheng, R.; Qian, Y.; Mi, J.; Wang, Y.; Liao, X.; Ma, B.; Zou, Y.; et al. Modified cornstalk biochar can reduce ammonia emissions from compost by increasing the number of ammonia-oxidizing bacteria and decreasing urease activity. Bioresour. Technol. 2021, 319, 124120.
81. Jia, X.; Wang, M.; Yuan, W.; Shah, S.; Shi, W.; Meng, X.; Ju, X.; Yang, B. N2O Emission and Nitrogen Transformation in Chicken Manure and Biochar Co-Composting. Trans. ASABE 2016, 59, 1277–1283.
82. Guo, H.; Gu, J.; Wang, X.; Yu, J.; Nasir, M.; Zhang, K.; Sun, W. Microbial driven reduction of N2O and NH3 emissions during composting: Effects of bamboo charcoal and bamboo vinegar. J. Hazard. Mater. 2019, 390, 121292.
83. Yang, Y.; Awasthi, M.K.; Wu, L.; Yan, Y.; Lv, J. Microbial driving mechanism of biochar and bean dregs on NH3 and N2O emissions during composting. Bioresour. Technol. 2020, 315, 123829.

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