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Abstract

This study investigated effects of mature compost on gaseous emissions during composting using pig manure amended with corn stalks. Apart from a control treatment, three treatments were conducted with the addition of 5% (wet weight of raw materials) of mature compost: (a) mixing raw materials with mature compost at the beginning of composting; (b) covering raw materials with mature compost throughout the experimental period; and (c) covering raw materials with mature compost at the start of composting, but incorporating it into composting pile on day 6 of composting. Mature compost used for the last treatment was inoculated with 2% (wet weight) of raw materials of strain M5 (a methanotrophic bacterium) solution. During 30-d of composting, three treatments with the addition of mature compost could reduce CH₄ emission by 53–64% and N₂O emission by 43–71%. However, covering with mature compost throughout the experimental period increased cumulative NH₃ emission by 61%, although it could reduce 34% NH₃ emission in the first 3 d. Inoculating strain M5 in mature compost covered on the top of composting pile within first 6 d enhanced CH₄ oxidation, but simultaneously increased N₂O emission. In addition, mixing with mature compost could improve compost maturity. Given the operational convenience in practice, covering with mature compost and then incorporating it into composting pile is a suitable approach to mitigate gaseous emissions during composting.

Keywords

emissions, during, composting, effects, mixing, covering, mature, compost, gaseous

Disciplines

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Effects of mixing and covering with mature compost on gaseous emissions during composting

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Abstract

This study investigated effects of mature compost on gaseous emissions during composting using pig manure amended with corn stalks. Apart from a control treatment, three treatments were conducted with the addition of 5% (wet weight of raw materials) of mature compost: a) mixing raw materials with mature compost at the beginning of composting; b) covering raw materials with mature compost throughout the experimental period; and c) covering raw materials with mature compost at the start of composting, but incorporating it into composting pile on day 6 of composting. Mature compost used for the last treatment was inoculated with 2% (wet weight) of raw materials of *strain M5* (a methanotrophic bacterium) solution. During 30-d of composting, three treatments with the addition of mature compost could reduce CH₄ emission by 53 to 64% and N₂O emission by 43 to 71%. However, covering with mature compost throughout the experimental period increased cumulative NH₃ emission by 61%, although it could reduce 34% NH₃ emission in the first 3 d. Inoculating

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strain M5 in mature compost covered on the top of composting pile within first 6 d enhanced CH_4 oxidation, but simultaneously increased N_2O emission. In addition, mixing with mature compost could improve compost maturity. Given the operational convenience in practice, covering with mature compost and then incorporating it into composting pile is a suitable approach to mitigate gaseous emissions during composting.

Key words: Composting; Greenhouse gases; Mature compost; Pig manure; Inoculation

1. Introduction

Composting is a promising technology for the treatment of livestock manures. During composting, organic materials are aerobically degraded by microorganisms, therefore significantly reducing the volume and mass of these organic wastes. Meanwhile, the pathogen-free, non-toxic and nutrient-rich end compost can be produced under certain conditions with sufficient composting time (Scheutz et al., 2011). However, considerable emissions of NH_3 , CH_4 and N_2O could occur during composting, which not only reduce the reusable nutrients in final compost but also lead to secondary pollution such as greenhouse effect, degrading environmental benefits of composting.

During composting, 9.6 to 46% of initial TN loss of raw materials is in form of NH_3 emission (Fukumoto et al., 2003; Morand et al., 2005; Jiang et al., 2011). The N_2O emission may constitute of 0.2 to 6% of initial TN loss of raw materials (Beck-Friis et al., 2001; Szanto et al., 2007). While forced aeration composting system has been widely applied, CH_4 emission accounts for 0.8 to 14% of initial carbon loss of raw materials due to partial anaerobic conditions in composting piles (Hao et al., 2004; Yamulki, 2006; Szanto et al., 2007; Jiang et al., 2011). Both N_2O and CH_4 are major greenhouse gases (GHGs), whose global warming

potential is 298 and 25 times higher than that of CO₂, respectively, based on a 100 years' time frame (IPCC, 2007). Therefore, it is necessary to mitigate these gaseous emissions to enhance environmental benefits of composting.

Biofiltration is an effective technique to mitigate gaseous emissions during composting. Filter materials, such as mature compost, can absorb gases that exhaust from composting piles. Diverse bacteria acclimated in filter materials can also contribute to the mitigation of gaseous emissions. Hong (2005) reported that using a medium depth of 500 mm of mature compost amended with coconut peels could completely remove NH₃ emitted from manure composting. In addition, mature compost of different waste materials has also been widely applied as a low-cost biocover material to minimize CH₄ emission from landfill sites (Barlaz et al., 2004; Stern et al., 2007; Scheutz et al., 2009). The large surface area and permeable pore space of mature compost can yield suitable conditions for methanotrophs proliferation, thus effectively oxidizing CH₄ (Scheutz et al., 2011). Furthermore, mature compost with sufficient water-holding capacity can keep covering materials at high water content, reducing the gaseous permeability or diffusion coefficients in covering layer (Stern et al., 2007).

Mature compost is an economical bulking agent to optimize composting process. Mixing mature compost with raw materials can improve inter-particle voids in composting pile, thus increasing air permeability (Iqbal et al., 2010). Because of the bulking property, mature compost could create a suitable environment for microbial growth in composting pile (Scheutz et al., 2009). Therefore, mature compost was also referred as to be an inoculating agent in many studies (Kato and Miura, 2008; Abichou et al., 2009). However, to our knowledge, the effects of direct addition of mature compost on gaseous emissions during composting have not yet been systematically studied. Therefore, this study aims to

comprehensively investigate the effects of mature compost on the emission profiles of NH_3 , N_2O and CH_4 during composting using a mixture of pig manure and corn stalks.

2. Materials and methods

2.1 Composting materials and setup

The raw material was a thorough mixture of pig manure and chopped corn stalks (< 80 mm in length) at a ratio of 7:1 (wet weight). Pig manure was obtained from a pig farm (Shujiatuo Town, Beijing, China) where the “ganqingfen” system was used. The “ganqingfen” system is solid animal excreta manually collected in the stables before flushing urine with water (Schuchardt et al., 2011). Chopped corn stalks were used as structural materials, collected from Shangzhuang Experimental Station, China Agricultural University, Beijing. Mature compost, which used the same raw materials as this study, was collected from a pilot composting box. The characteristics of raw materials and mature compost are given in Table 1.

[TABLE 1]

[FIGURE 1]

A series of 60 L composting vessels were used in this study to simulate the forced-draft aeration system (Fig. 1). The aeration rate was set at $0.48 \text{ L kg}^{-1} \text{ DM}^{-1} \text{ min}^{-1}$. A C-LGX program was used to intermittently interrupt the aeration for 5 min every 25 min, and automatically record temperature in the centre and top of composting pile.

2.2 Experimental protocol

Four treatments with three replicates were carried out, namely CK, Mix, Cover and Cover + Mix. 5% (wet weight of raw materials) of mature compost was used as an additive. The CK was a control treatment without the addition of mature compost. Mix was the treatment that

thoroughly mixed mature compost with raw materials at the start of composting. Cover was the treatment that used mature compost to cover composting pile throughout the experimental period, whereas Cover + Mix was the treatment that mature compost was covered on the top of composting pile within first 6-d of composting, and subsequently was incorporated into composting pile by manual turning. The mature compost used in Cover + Mix treatment was inoculated 2% (wet weight of raw materials) of *strain M5* solution. According to Deng (2012), *Strain M5* is a methanotrophic bacterium, *Ochrobactrum tritici*, characterized as Gram-positive. This bacterium could take methane as the sole carbon source. The optimum temperature and pH for the growth of *Strain M5* are 30 °C and pH 7-9, respectively (Deng, 2012).

The composting system was operated for 30 d. Composting piles were turned manually on day 6, 12, 18 and 24. Mature compost covered on the top of composting pile in Cover treatment was also turned separately. Solid samples (0.42 kg) were collected homogeneously based on the board type sampling method after thoroughly mixing raw materials outside of composting vessels at the start, final and turning day of experiment. A part of samples were air-dried and others were stored at 4 °C for analysis.

2.3 Analytical methods

Gas samples were collected and analysed three times per day according to Luo et al. (2013). The N₂O and CH₄ were analysed by gas chromatograph (3420A, Beifen, China) according to Jiang et al. (2011). Ammonia was measured via washing bottle with boric acid and titrated against H₂SO₄. The CO₂ and O₂ were measured by a CO₂/O₂ detector (BIOGAS-5000, Geotech). The TKN and TOC of compost samples were measured by the Kjeldahl method and potassium dichromate titrimetric method, respectively, according to Chinese national standard of organic fertilizer (NY 525-2012). Moisture content was determined after drying

at 105 °C to constant weight. Inorganic nitrogen species (NH_4^+ , NO_3^- , NO_2^-) were extracted by 2 M KCl (10:1, v/w), and then analysed by a segmented-flow analyzer (Auto Analyzer 3, Seal, Germany). Germination index (GI) was measured and calculated according to Guo et al. (2012).

The mean value and standard deviation of three replicates of each treatment were reported. Statistical Analysis System 8.2 for Windows was used for the variance analysis.

3. Results and discussion

3.1 Evaluation of composting performance

A typical composting period is generally divided into mesophilic, thermophilic, and curing phase with the biodegradation of organic materials. The temperature of all treatments increased to over 55 °C (thermophilic phase) within first 2 d, and remained above this level for at least 12 d (Fig. 2a), indicating the active biodegradation of organic matters. With the gradual depletion of biodegradable organics, all treatments experienced a decline in temperature and entered curing phase. However, the temperature of treatments with mature compost was higher than that of CK in curing phase (Fig. 2a), possibly due to the reduction of heat loss with the addition of mature compost. Nevertheless, all treatments were converged towards the ambient temperature on day 29, implying the end of composting.

[FIGURE 2]

Oxygen contents of all treatments decreased rapidly when composting started (Fig. 2b), due to oxygen consumption by aerobic microorganisms for biodegrading organic matters. Subsequently, all treatments experienced an increase in oxygen content under forced aeration conditions, interrupted temporarily after manual turning. After 18-d of composting, oxygen contents of all treatments were up to ambient level except for Cover treatment. Given the relatively high temperature of this treatment (Fig. 2b), biological activity has been still active,

maintaining the consumption of oxygen. Nevertheless, its oxygen content reached the ambient level at the end of composting.

The GI values of all treatments gradually increased with composting (Fig. 2c). The changes of GI were in good agreement with previous studies (Guo et al., 2012; Jiang et al., 2013). At the end of composting, GI values of all treatments attained more than 90%, indicating the maturity of compost. Compared to CK, Mix and Cover + Mix treatment could increase the final GI by 14% and 10%, respectively. This was probably due to the improvement in decomposition of toxic substances after mixing or incorporating mature compost with raw materials.

3.2 Gaseous emissions

3.2.1 Ammonia emission

The dominant emissions of NH_3 for all treatments occurred in the thermophilic phase and peaked at day 5-6 (Fig. 3a). That could be attributed to the biodegradation of organic nitrogen to inorganic nitrogen such as NH_4^+ which could volatilize in form of NH_3 under high temperature and pH (pH = 7-9 in this study). The decomposition of organic matter was also accompanied by a rise in pH of the composting pile (Fig. 2d), which in turn favoured the volatilization of NH_3 . In the first 3 d, compared to CK, treatments with the addition of mature compost reduced NH_3 emission by 14 to 38%, possibly due to the high adsorptive capacity of mature compost. Cover + Mix treatment reduced NH_3 emission by 38% which was a slightly greater reduction than 34% by Cover treatment (Fig. 3b). The only difference between these two treatments within first 3 d was whether mature compost was inoculated with *strain M5* or not. Therefore, the slightly greater reduction of NH_3 emission could be hypothesized as the oxidation of NH_3 by *strain M5*. In fact, the oxidization of NH_3 to N_2O by methanotrophic bacteria has been reported in numerous studies (Joshua, 2000; Szanto et al., 2007). This

hypothesis could also be confirmed by the observation that the N_2O emission in Cover + Mix treatment was higher than that in Cover treatment within first 3 d (see section 3.2.2). Nevertheless, future study is expected to further investigate the effects of *strain M5* on NH_3 emission during composting.

[FIGURE 3]

The NH_3 emissions of three treatments with the addition of mature compost increased from day 4 onward (Fig. 3a). As a result, over 30-d of composting, Cover treatment increased the total cumulative NH_3 emission by approximately 61% compared to CK (Fig. 3b). Slight increases were also observed for Mix and Cover + Mix treatment (0.4% and 4%, respectively). The statistical analysis results showed significant differences between the Cover and CK treatment ($P < 0.01$), but no significant differences were found among treatments CK, Mix and Cover + Mix. This result was different from a previous study by Hong (2005) who observed effective removal of NH_3 emission through compost biofiltration. Because mature compost was directly covered on the top of the composting pile in Cover treatment of our study, this discrepancy could be attributed to the possibility that NH_4^+ in mature compost (4.3 g kg^{-1} on dry matter basis) volatilized as NH_3 under high temperature and appropriate pH. The insignificant differences of initial TN loss of raw materials between Cover and CK treatment (Table 2) also indicated that the increase of NH_3 emission was possibly from the covering layer.

3.2.2 Nitrous oxide emission

The emission of N_2O for all treatments occurred predominantly in the first 4-9 d (Fig. 4b), which was consistent with previous studies. According to previous studies, there are two possible mechanisms for this phenomenon: nitrification or denitrification could occur in raw materials before the start of composting (Sommer and Moller, 2000; El Kader et al., 2007);

the initial temperature and oxygen concentration are favourable to nitrifiers on the surface of composting piles (Hao et al., 2004).

[FIGURE 4]

Compared to CK, Cover treatment reduced N_2O emission by 73% in first 4 d (Fig. 4b), possibly due to the blockage of gaseous permeation by the covering layer. Conversely, Cover + Mix treatment increased N_2O emission by approximately 8% in comparison to CK. As discussed in section 3.2.1, this might be due to the oxidation of NH_3 to N_2O by *strain M5* that was inoculated with mature compost of Cover + Mix treatment. However, this treatment could effectively reduce N_2O emission when mature compost was incorporated into composting pile, achieving 43% of overall reduction compared to CK. This was similar to the mitigation efficiency by Mix treatment (46%). Since mixing or incorporating mature compost with raw materials could improve air permeability in composting piles (Fig. 2b), denitrification could probably be restrained, thus reducing N_2O emission. However, no clear distinction in N_2O emission between treatments Mix and Cover + Mix from day 6 onward indicated that the activity of *strain M5* could possibly be inhibited under high temperature in the interior of composting pile.

Three treatments with the addition of mature compost could reduce N_2O emissions by 43 to 71% over 30-d of composting in comparison with CK (Fig. 4b). This result was in contrast to Maeda et al. (2010) who observed slight promotions of N_2O emissions by covering and mixing with mature compost during dairy cattle composting. Given the differences in raw materials and composting processes, this contrast was explainable. In their study, large composting piles without aeration systems led to an obligatory anoxic condition for denitrification and therefore increased N_2O emission (Maeda et al., 2010).

3.2.3 Methane emission

The CH₄ emissions of all treatments mainly occurred during thermophilic phase of composting (Fig. 5a). In the thermophilic phase, microorganisms could rapidly degrade organics, leading to the consumption of oxygen exceeding the supply via forced aeration system (Manios et al., 2007; Jiang et al., 2013). Therefore, partially anaerobic conditions were developed in composting heaps for the production of CH₄. With the biodegradation of organic matters, all treatments experienced a gradual decline in CH₄ emission (Fig. 5a), whereas oxygen contents increased simultaneously (Fig. 2b). Manual turning could improve the biodegradation of organic matters, therefore temporarily increasing CH₄ emissions (Fig. 5a).

[FIGURE 5]

Over 30-d of composting, Cover treatment could reduce CH₄ emission by 59% compared to CK (Fig. 5b). This result was in consistent to previous studies that investigated the performance of mature compost as biocover material in landfill sites (Stern et al., 2007; Abichou et al., 2009). Since mature compost possesses properties of large surface area and permeable pore space, it could yield a suitable environment for methanotrophs growth, thus enhancing CH₄ oxidation (Scheutz et al., 2011). Within first 6 d, Cover + Mix treatment could reduce CH₄ emission by 52% which was higher than the reduction by Cover treatment (44%). Because *strain M5* inoculated in mature compost of Cover + Mix treatment is a methanotrophic bacterium, this improved reduction could be expected. When the mature compost was incorporated into composting pile from day 6 onward, the oxygen permeability in composting pile was improved (Fig. 2b). Therefore, the reduction of CH₄ emission for Cover + Mix treatment increased to 65% over 30-d of composting. This can also explain 53% reduction of CH₄ emission for Mix treatment.

3.3 Carbon and nitrogen balances and GHG emissions

The major pathway for the loss of initial TOC of raw materials was in form of CO₂ (41 to 50%), whereas 0.3 to 0.9% of initial TOC of raw material was lost due to CH₄ emission under partially anaerobic conditions in composting piles (Table 2). Either mixing or covering with mature compost could effectively reduce CH₄ emission, possibly due to the bulky property and highly adsorptive capacity of mature compost.

[TABLE 2]

The TN losses of all treatments ranged from 28 to 37% of initial TN of raw materials (Table 2). Only 28% of initial TN was lost for Cover + Mix treatment. However, it should be noted that this value cannot reflect the actual TN loss of raw materials as the TN content was increased after mature compost was incorporated into composting pile. As a major pathway for initial TN loss, NH₃ emissions of all treatments accounted for 24 to 33%. The highest NH₃ emission was observed for Cover treatment. However, this might be due to the ammonification of organic nitrogen in the covering layer rather than in the underlying composting pile, given no significant difference in initial TN loss of raw materials between CK and Cover treatment based on our statistical analysis. Only 0.5 to 1.7% of initial TN of raw materials was lost by N₂O emission. These results were similar to the study by Wolter et al. (2004) who observed that 0.1 to 1.9% of initial TN of raw materials was lost in the form of N₂O emission.

While CO₂, CH₄ and N₂O are all important GHGs, the contribution of CO₂ to greenhouse effect should be excluded during composting as it derives from microbial respiration (IPCC, 2007). Therefore, only CH₄ and N₂O were taken into consideration when calculated the total GHG emissions in this study. The total GHG emissions ranged from 61 to 210 kg CO₂-eq t⁻¹ DM⁻¹. Compared to CK, treatments with the addition of mature compost could reduce total GHG emissions by 48-71%.

4. Conclusion

Mixing and covering with mature compost could effectively control GHG emissions during composting. Inoculating a methanotrophic bacterium, *strain M5*, in mature compost that covered on the top of composting pile could reduce CH₄ emission, but simultaneously increased N₂O emission. Without any microbial inoculation, mature compost covered on the top of composting pile could effectively reduce NH₃ emission in the first 3-d of composting, but thereafter increased NH₃ emission. Mixing with mature compost could also improve compost maturity. Considering the operational convenience, covering with mature compost and then incorporating it into composting pile is a suitable way to control the gaseous emissions during composting in practice.

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Fig.1 Sketch map of a closed composting vessel. PI: pressure indicator; FI: flow indicator; TIR: temperature information recorder; QI: quantity indicator; GC: gas chromatograph; D: CO₂/O₂ detector

Fig. 2 Profiles of temperature (a), oxygen content (b), GI (c) and pH (d) during composting. Error bars in (c) and (d) represent standard deviations of mean values (n = 3); standard deviations of mean values (n = 3) of temperature (a) and oxygen content (b) were in the range of 0.1-14.9 °C and 0-5.6%, respectively.

Fig. 3 Changes of emission (a) and cumulative emission (b) of NH₃ during composting. Standard deviations of mean values (n = 9) of emission (a) and cumulative emission (b) of NH₃ were in the range of 0.02-0.84 g NH₃-N kg⁻¹ DM⁻¹ d⁻¹ and 0.05-1.49 g NH₃-N kg⁻¹ DM⁻¹, respectively.

Fig. 4 Changes of emission (a) and cumulative emission (b) of N₂O during composting. Standard deviations of mean values (n = 9) of emission (a) and cumulative emission (b) of N₂O were in the range of 0.01-0.07 g N₂O-N kg⁻¹ DM⁻¹ d⁻¹ and 0.01-0.19 g N₂O-N kg⁻¹ DM⁻¹, respectively.

Fig. 5 Changes of emission (a) and cumulative emission (b) of CH₄ during composting. Standard deviations of mean values (n = 9) of emission and cumulative emission (b) of CH₄ were in the range of 0.06-0.52 g CH₄-C kg⁻¹ DM⁻¹ d⁻¹ and 0.11-0.97 g CH₄-C kg⁻¹ DM⁻¹, respectively.

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Fig.1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

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Table 1 Characteristics of raw materials and mature compost for composting

Materials	TOC ^a	TKN ^a	NH ₄ ⁺ -N	NO ₂ ⁻ -N + NO ₃ ⁻ -N	Moisture	C/N
	(g kg ⁻¹) ^a		(mg kg ⁻¹) ^a		(%)	
Pig faece	363	28.4	4300	80	79.8	12.8
Corn stalks	414	9.6	-	-	4.8	43.2
Mature compost	290	26.9	2800	350	16.8	10.8

^a TOC: total organic carbon; TKN: total Kjeldahl nitrogen; Values were on dry matter basis.

Table 2 Carbon and nitrogen balances and total greenhouse gas emissions

Treatment	Carbon balance (%) ^a			Nitrogen balance (%) ^b			GHG emissions ^c		
	CO ₂ -C ^d	CH ₄ -C	TOC loss	N ₂ O-N	NH ₃ -N	TN loss	CH ₄	N ₂ O	Total GHG
CK	45 b	0.9 a	52 a	1.7 a	25 b	37 a	100 a	109 a	209 a
Mix	50 a	0.4 b	55 a	0.9 b	23 b	36 a	48 b	60 b	108 b
Cover	41 b	0.3 c	46 b	0.5 c	33 a	38 a	35 c	26 c	61 c
Cover + Mix	44 b	0.3 c	51 a	0.9 b	25 b	28 b	34 c	59 b	93 b

^{a, b} Percentages of initial total organic carbon and total nitrogen of raw materials, respectively, dry weight basis.

^c GHG emission: greenhouse gas emission in the unit of kg CO₂-eq t⁻¹ on dry matter basis.

^d Values followed by different letters within a column differ significantly at the 0.05 probability level.