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## **Ammonia and greenhouse gas emissions from co-composting of dead hens with manure as affected by forced aeration rate**

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**Abstract.** *The effect of ventilation rate (VR) on ammonia (NH<sub>3</sub>) and greenhouse gas (GHG) emissions from composting piles of dead hens mixed with hen manure was quantified by measuring the gaseous concentrations and airflow rate through the compost bins. Three VR levels of 0.9, 0.7 and 0.5 m<sup>3</sup>/hr/bin (equivalent to the air exchanges per hour of 0.9, 0.7 and 0.5) were evaluated, each with three replicates. The compost piles were turned once (on day 58) during the 11-wk composting period. Gaseous concentrations of the inlet and exhaust air of the compost bins were measured using a multi-gas infrared photoacoustic analyzer coupled with a multi-channel sampler; VR was measured with a flow meter; and the emission rate (ER) of each gas was computed from the VR and the gas concentration. Decomposition of the carcass over the 11-wk composting period was found to be greater than 88%, as assessed by the reduction in carcass mass. NH<sub>3</sub> ER was relatively stable when the compost pile was at high temperatures (~60°C). Sharp increase in carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) emissions occurred quickly after construction of the compost pile. VR was found to significantly affect NH<sub>3</sub>, CO<sub>2</sub> and CH<sub>4</sub> emissions (p<0.05). Specifically, cumulative emissions per kg of initial co-compost matter for the three*

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*VR of 0.9, 0.7 and 0.5 m<sup>3</sup>/hr/bin were, respectively, 2.4, 2.0 and 1.2 g NH<sub>3</sub>; 78, 66 and 42 g CO<sub>2</sub>; 120, 90 and 52 mg CH<sub>4</sub>; and 6.4, 6.1 and 5.1 mg N<sub>2</sub>O. Hence, the study results suggest that the rate of forced aeration can be adjusted to reduce NH<sub>3</sub> and GHG emissions from animal mortality composting.*

**Keywords.** NH<sub>3</sub>; Greenhouse gas; Dead hens; Aeration rate; Composting.

## Introduction

Proper disposal of animal mortality is crucial to sustaining animal industries, improving public health and protecting the environment. Different disposal methods or practices have been used by the animal industry, such as incineration, burial, rendering, anaerobic digestion, and composting. Among these methods composting has been demonstrated to be environmentally sound and economically viable when operated under proper management. Composting of dead poultry, livestock or slaughter waste under temperate conditions have been reported in the literature (Sivakumar et al., 2008; Xu et al., 2007; Xu et al., 2011; Hao et al., 2009).

Associated with manure management such as composting is the generation of certain noxious gases (e.g., ammonia, hydrogen sulfide) and greenhouse gases (GHG). For instance, about 869 Gg of methane (CH<sub>4</sub>) and 44 Gg of nitrous oxide (N<sub>2</sub>O) are emitted from livestock manure management in China, accounting for 2.53% of the total CH<sub>4</sub> and 5.18% of the total N<sub>2</sub>O emissions in 1994 (The People's Republic of China Initial National Communications on Climate Change, 2004). There are a number of factors involved in composting that could affect the magnitude of the gaseous emissions, such as the scale of operation, process temperature (Pagans et al., 2006; Marsumura et al., 2010), ventilation or aeration rate (Li et al., 2008; Ahn et al., 2007), and management and amendments (Tamura and Osada, 2006; Yasuda et al., 2009; Fukumoto et al., 2003; Ahn et al., 2011; Szanto et al., 2007; Kader et al., 2007). Co-composting livestock mortalities with manure could affect the composting process and the rate of greenhouse gas (GHG) emission, given that carcasses have much higher C, N and moisture contents than does most livestock manure. Xu et al. (2007) and Hao et al. (2009) reported a significant increase in GHG emissions when cattle mortality and slaughter waste were co-composted with manure. Aeration (pile mixing or forced aeration), in addition to moisture content and C/N ratio of the composting materials, is an important factor influencing NH<sub>3</sub> and GHG emissions, cost and compost quality of the composting process (Ahn et al., 2011).

Although considerable research on composting of various organic wastes has been conducted, little information exists on co-composting of dead hens with livestock manure and the associated operational parameters on NH<sub>3</sub> and GHG emissions. Hence the objective of this study was to evaluate the effect of forced aeration or ventilation rate (VR) on the characteristics of co-composting dead hens with manure in terms of composting temperature, emission of NH<sub>3</sub> and GHG, and the properties of final compost product. The research information would provide insight toward design and operational guidelines for effective co-composting of hen mortalities with manure that will lead to reduced gaseous emissions while achieving the desired final compost product.

## Methods and Materials

### *Experimental design and facility*

The study was carried out from 9 April to 25 June 2010 (late spring to early summer) in a field experiment station at the Institute of Environment and Sustainable Development in Agriculture (IEDA, CAAS), Beijing, China. The average ambient temperature during the measurement period was 19.8 °C (SD of 6.1 °C, maximum of 28.2 °C and minimum of 6.5 °C). Fresh laying-hen manure and dead birds were collected from a commercial farm in suburban Beijing that was about 100 km from the experiment site. The hen manure was mixed with chopped cornstalk (~2 cm) to achieve a mixture moisture content (MC) of about 65%. Nine composting bins, each measuring 1 m × 1 m × 1 m (1 m<sup>3</sup> volume), were designed and built for this study. Approximately 10 cm of the chopped cornstalk was placed on the bottom of each compost bin, followed by

addition of 40 cm of manure-chopped cornstalk mixture, then side-by-side placement of about 15 dead mature hens (~2 kg/bird) in the middle of each compost bin, and finally covered with the manure-cornstalk mixture. The total initial compost pile had a height of about 80 cm and weight of about 475 kg.

Forced aeration was applied to the compost piles, where fresh air was introduced into each bin through an air distribution plate near the bottom of the compost bin, through the compost pile and was exhausted through the top outlet on the bin cover. The aeration air was provided by a common air pump that was connected to a distribution manifold that further divided the main supply air via 9 identical flow meters at three VR of 0.9, 0.7 and 0.5 m<sup>3</sup>/(hr-bin) (Trt1, Trt2 and Trt3, respectively), with each VR replicating 3 times. The corresponding air changes per hour (ACH) for the three VR levels were 0.9, 0.7 and 0.5. The air supply pump for each treatment was controlled by a timer to operate at 10-min and 20-min off cycles. The compost piles were remixed and reconstructed once on day 58 during the 11-wk study. A schematic representation of the experimental setup is shown in Fig. 1.

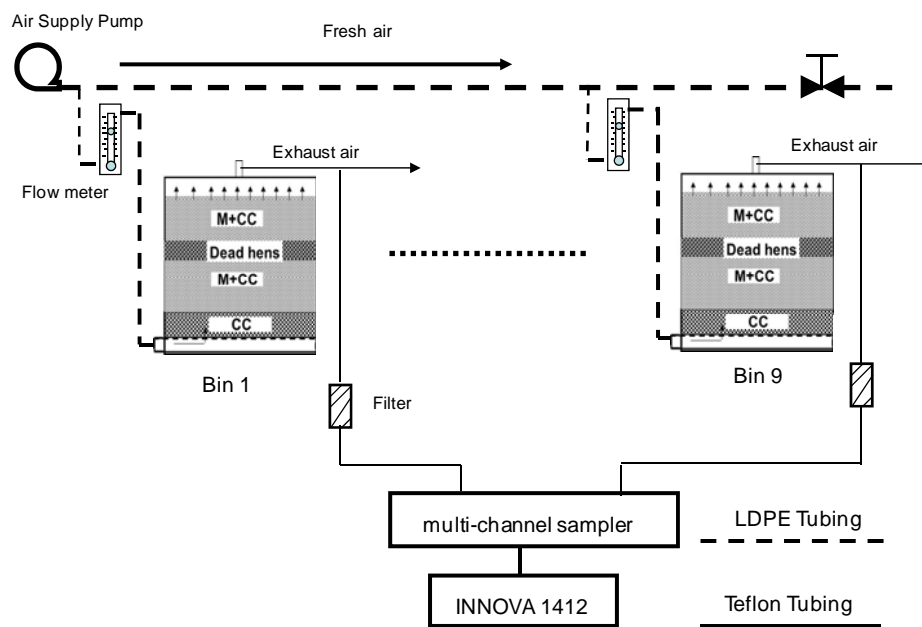


Fig. 1. Schematic representation of the composting experimental setup(M = hen manure, CC = chopped cornstalk)

### Gas sampling system

A photoacoustic infrared multi-gas analyzer (model 1412, Innova AirTech Instrument, Ballerup, Denmark) along with a multi-channel sampler (Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences, Beijing, China) was used to successively take samples from the 9 compost bins exhaust outlets and the common air inlet. Before measurement, the multi-gas analyzer was checked and calibrated, as needed, using individual CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, and NH<sub>3</sub> standard calibration gases procured from the National Standard Material Center in Beijing (China). For each of the 9 air samplings, five 2-min measurement cycles were completed by the gas analyzer, with the first four cycles for stabilization and the fifth cycle reading as the measured value. Thus, it took a total of 1.5 h to complete one sampling cycle. The fresh air concentration was measured for half hour each day using the ninth sampling channel and the result showed the fresh air concentration was kept constant during the experiment period.

Compost temperature was recorded at the dead birds depth at 1-h intervals throughout the experiment using portable temperature loggers (Hobo Pro v2 U23, Onset Computer Corp., Bourne, Massachusetts, USA). The ambient air temperature data were obtained from Beijing weather station that was located about 4 km from the experiment site (China Meteorological Data Sharing Service System).

### ***Compost sample analysis***

Composting samples from the initial and final compost were collected and analyzed. To account for potential heterogeneity within the compost bins, duplicate samples were collected from well mixed compost material within each bin. The samples were analyzed for physical and chemical properties, including MC, organic matter (OM), total carbon (TC), and total nitrogen (TN). MC and OM content were analyzed according to the national standards (NY 525-2002, 2002). TC and TN were analyzed using an elemental analyzer (PE2400 Series II CHNS System, PerkinElmer Inc., Massachusetts, USA). All analyses were carried out in duplicate, and the values were given as average of the two samples results for each bin.

### ***Estimation of NH<sub>3</sub> and GHG emission rate (ER)***

The total NH<sub>3</sub> and GHG emissions over the composting period were expressed on the basis of per kg initial material weight. With the knowledge of airflow rate, gas concentrations of inlet and outlet air and compost weight, GHG ER from the compost bins was calculated using the following equation:

$$ER = (C_o - C_i) \times Q_{air} / W \quad (1)$$

where: *ER* is the NH<sub>3</sub> or GHG emission rate per kg initial compost weight, mg/(kg-hr); *C<sub>i</sub>* and *C<sub>o</sub>* are NH<sub>3</sub> or GHG concentrations of the inlet and outlet air, respectively, mg/m<sup>3</sup>; *Q<sub>air</sub>* is VR of the compost bin, m<sup>3</sup>/hr; and *W* is initial compost weight, kg.

### ***Statistical analysis***

The response variables for different VR regimens were analyzed using Proc GLM test in SAS (SAS Institute, Carey, NC, USA, 2001) to determine the treatment effect.

## **Results and discussion**

### ***Temperature characteristics of the compost bins***

The temperature profiles of the composting bins aerated at different rates or VR are shown in Fig. 2. Upon starting of the composting, the temperature increased quickly in all the bins, peaked at 71.4±0.6, 70.6±0.4, and 71.5±1.8 (mean±SD) on day 4, 5 and 4 for the 0.9, 0.7 and 0.5 m<sup>3</sup>/(hr-bin) VR, respectively. Then the temperature slowly declined to 60 °C by day 18 (Trt1) to day 38 (Trt2). The temperature increased again after the remixing but only lasted 1 day over 60 °C and dropped slowly to ambient temperatures. Compared to the VR of 0.9 m<sup>3</sup>/(hr-bin), the VR of 0.7 and 0.5 m<sup>3</sup>/(hr-bin) maintained longer time of high temperatures (>60 °C) (38 days for Trt2 and 31 days for Trt3, respectively). The shorter retention time of high temperatures with the higher VR of 0.9 m<sup>3</sup>/(hr-bin) presumably arose from the excessive airflow which caused excessive heat loss from the composting bins. Li et al. (2008) reported the similar trend.

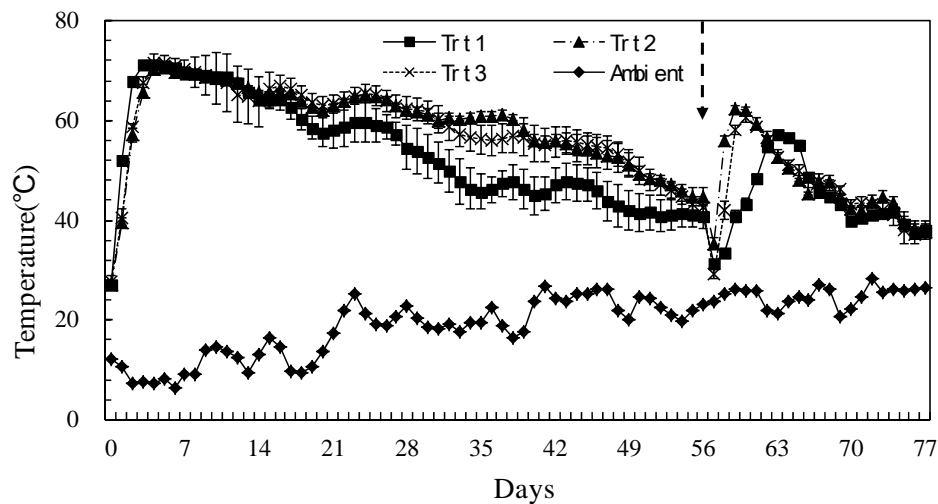


Fig. 2 Effect of aeration or ventilation rate (VR) on composting temperatures measured at the dead birds depth (VR = 0.9, 0.7, and 0.5 m<sup>3</sup>/(hr-bin) for Trt1, Trt2 and Trt3, respectively). The vertical arrow line stands for remixing of the compost piles.

### ***Manure and compost properties***

The compost properties at the start and the end of the 11-week composting period under different VR regimens are presented in Table 1. As shown by the data, there were no noticeable differences in the final weight, MC, OM, TC or TN content of the compost among the three VR regimens, Approximately 38.6-43.4% of the initial dry matter weight and 52.1-53.4% of the initial TN were lost during the composting. These values were somewhat higher than those reported by Fukumoto et al. (2003). The amount of carcass residuals for Trt3 (0.5 m<sup>3</sup>/hr/bin) was noticeably higher as compared with that of Trt1 or Trt2, although all three treatments had a decomposition rate of > 88%, as assessed by reduction in carcass weight. Most soft tissues of the carcasses had degraded and there was no visible separation of carcasses from manure except for some bones and feathers. The lower decomposition rate under the low VR might have arose from insufficient aeration. Composting requires oxygen for aerobic activity, and too low aeration would lead to anaerobic conditions. However, too much aeration would lead to excessive cooling, preventing the thermophilic conditions required for optimum rate of decomposition. Between these two extremes is an optimum aeration rate, which provides sufficient oxygen for aerobic decomposition while keeping the temperatures in the thermophilic range (Ahn et al., 2007). The result suggested that among the three tested VR the middle value (0.7 m<sup>3</sup>/hr) (Trt2) was most suitable for the forced aeration composting under the current experimental conditions.

Table 1 Characteristics of the initial and final compost materials under different ventilation rates (VR) through a 1 m<sup>3</sup> compost bin<sup>A</sup> (n = 3)

Stage	Trt#	VR (m <sup>3</sup> /h)	Compost material (kg/bin)	Dead hens (kg/bin)	Moisture content (% w.b. <sup>B</sup> )	OM (% d.b. <sup>C</sup> )	TC (% d.b.)	TN (% d.b.)
Initial	Trt1	0.9	475±0.2	28.5±0.2	63.1±0.1	48.1±1.1	30.9±0.3	4.43±0.1
	Trt2	0.7	475±0.2	27.6±0.2	63.1±0.1	48.1±1.1	30.9±0.3	4.43±0.1
	Trt3	0.5	475±0.1	28.4±0.1	63.1±0.1	48.1±1.1	30.9±0.3	4.43±0.1
Final <sup>D</sup>	Trt1	0.9	234±12.4 <sup>a</sup>	2.7±0.1 <sup>a</sup>	57.6±0.3 <sup>a</sup>	40.3±2.2 <sup>a</sup>	24.1±0.6 <sup>a</sup>	2.05±0.02 <sup>a</sup>
	Trt2	0.7	255±26.3 <sup>a</sup>	2.8±0.2 <sup>a</sup>	58.4±0.8 <sup>a</sup>	42.2±0.7 <sup>a</sup>	24.6±0.3 <sup>a</sup>	2.12±0.07 <sup>a</sup>
	Trt3	0.5	265±7.5 <sup>a</sup>	3.4±0.2 <sup>b</sup>	59.4±0.6 <sup>a</sup>	45.0±0.5 <sup>a</sup>	25.4±1.1 <sup>a</sup>	2.11±0.07 <sup>a</sup>

<sup>A</sup> Values are means±SE

<sup>B</sup> w.b., Wet basis

<sup>C</sup> d.b., Dry basis

<sup>D</sup> Means in the same column with different letters are significantly different ( $p<0.05$ ).

### **Patterns of gaseous emissions**

NH<sub>3</sub> concentration remained quite high during the period of high temperature of the composting material in all regimens (Fig. 3a). The NH<sub>3</sub> emission patterns observed in the current study agreed with that reported by Fukumoto et al. (2003). NH<sub>3</sub> emission slowly decreased before the remixing. The NH<sub>3</sub> concentration reached the high level again after the remixing, then quickly decreased to lower levels. After 11 weeks of composting, NH<sub>3</sub> emission almost ceased in all treatments.

The CO<sub>2</sub> emission pattern observed in the three VR regimens resembled that reported by Ahn et al. (2011) and Hao et al. (2009). CO<sub>2</sub> concentration from the compost bins peaked within 2-4 days after construction of the compost pile and gradually decreased (Fig. 3b). The CO<sub>2</sub> concentration reached another peak after the remixing and then quickly decreased. The CO<sub>2</sub> emission patterns were similar for all three VR regimens.

The CH<sub>4</sub> emission pattern observed in the three VR regimens resembled that reported by Fukumoto et al. (2003) and Ahn et al. (2011). CH<sub>4</sub> concentration from the compost bins peaked shortly after construction of the piles, then quickly decreased and remained low until the time of remixing (Fig. 3c). The CH<sub>4</sub> concentration increased again after the remixing and quickly decreased to low levels. It was speculated that the central region of the compost pile was under anaerobic conditions due to lack of oxygen in the beginning, hence more CH<sub>4</sub> production. With the supply of fresh air into the bins, the condition became more aerobic, hence reduced CH<sub>4</sub> generation. Once again the CH<sub>4</sub> emission patterns were similar for all three VR regimens.

N<sub>2</sub>O concentration from the compost bins peaked right after construction of the pile and quickly decreased to the ambient level (Fig. 3d). Remixing had no impact on the N<sub>2</sub>O concentration. This result did not resemble the pattern reported by Fukumoto et al. (2003) and Ahn et al. (2011) who observed most N<sub>2</sub>O emission occurring during the late composting period. The difference in the outcome could have been attributed to the difference in the microenvironment in the pile that was likely more aerobic for the current study due to the forced aeration while those in the studies by Fukumoto et al. (2003) and Ahn et al. (2011) were likely more anaerobic.

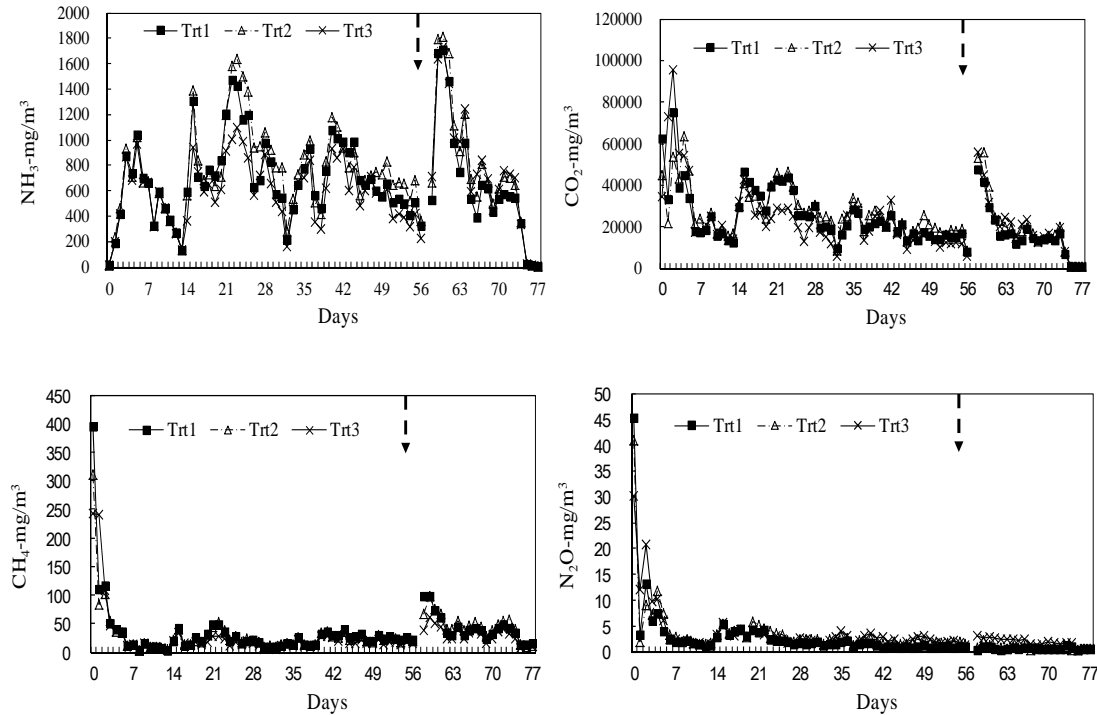


Fig. 3. Exhaust air concentrations of NH<sub>3</sub> (a), CO<sub>2</sub> (b), CH<sub>4</sub> (c) and N<sub>2</sub>O (d) under VR of 0.9 (Trt1), 0.7 (Trt2) or 0.5 (Trt3) m<sup>3</sup>/(hr-bin) during the mechanically aerated composting experiment. Down arrows indicate remixing of the compost piles.

### ***Effect of VR on GHG and NH<sub>3</sub> emissions***

The cumulative CO<sub>2</sub>, CH<sub>4</sub> and NH<sub>3</sub> emissions over the 11-wk composting period were significantly affected by the VR ( $P < 0.05$ ), although cumulative N<sub>2</sub>O was not ( $P = 0.22-0.84$ ) (table 2). Higher VR led to higher cumulative gaseous emissions. Hence, keeping VR as low as possible while achieving the good composting conditions would be conducive to saving energy and reducing gaseous emissions.

The cumulative gaseous emissions vs. time of composting were showed in Fig. 4, Higher emissions were found during the first 10 days for CO<sub>2</sub> (19.9-26.5%), CH<sub>4</sub> (26.5-30.1%) and N<sub>2</sub>O (46.0-57.9%). The higher emissions presumably arose from lower oxygen in the compost piles at the start. NH<sub>3</sub> emission remained quite constant throughout the whole composting period (Fig 4). The CO<sub>2</sub> emission accounted for about 99.6% of the total C loss, while the CH<sub>4</sub> emission accounted about 0.4% of total C loss. The CH<sub>4</sub> emission contribution to the total C loss was much lower than the reported 3.1-3.9% by Hu et al. (2007). The difference presumably resulted from the different composting methods involved, i.e., forced aeration (current study) vs. static piles (Hu et al.'s study). The CO<sub>2</sub> emission accounted for 10.1-18.6% of initial TC which was higher than reported values under static pile composting (Hao et al., 2009). The NH<sub>3</sub> emission accounted about 99.8% of total N loss, whereas the N<sub>2</sub>O emission accounted for about 0.2% of total N loss.



Table 2 Effect of ventilation rate (VR) on cumulative greenhouse gas and NH<sub>3</sub> emissions during 11-wk co-composting of dead hens with hen manure, expressed as amount per kg of initial compost material

VR (m <sup>3</sup> /hr/bin)	CO <sub>2</sub> (g/kg) <sup>A,B</sup>	CH <sub>4</sub> (mg/kg)	N <sub>2</sub> O (mg/kg)	CO <sub>2</sub> - eq(g/kg) <sup>D</sup>	NH <sub>3</sub> (g/kg)
0.9	78±0.8a <sup>C</sup>	120±7.7a	6.4±0.6a	82±0.6a	2.4±0.08a
0.7	66±1.7b	90±11.3b	6.1±0.5a	70±2.2b	2.0±0.03b
0.5	42±2.2c	52±2.9c	5.1±0.8a	45±2.4c	1.20.06c

<sup>A</sup> the cumulative gas emission is based on initial fresh composting material

<sup>B</sup> Means with different letters are significantly different ( $p < 0.05$ )

<sup>C</sup> Values are means±SE of 3 replicate bins

<sup>D</sup> GWP of 25 for CH<sub>4</sub> and 310 for N<sub>2</sub>O

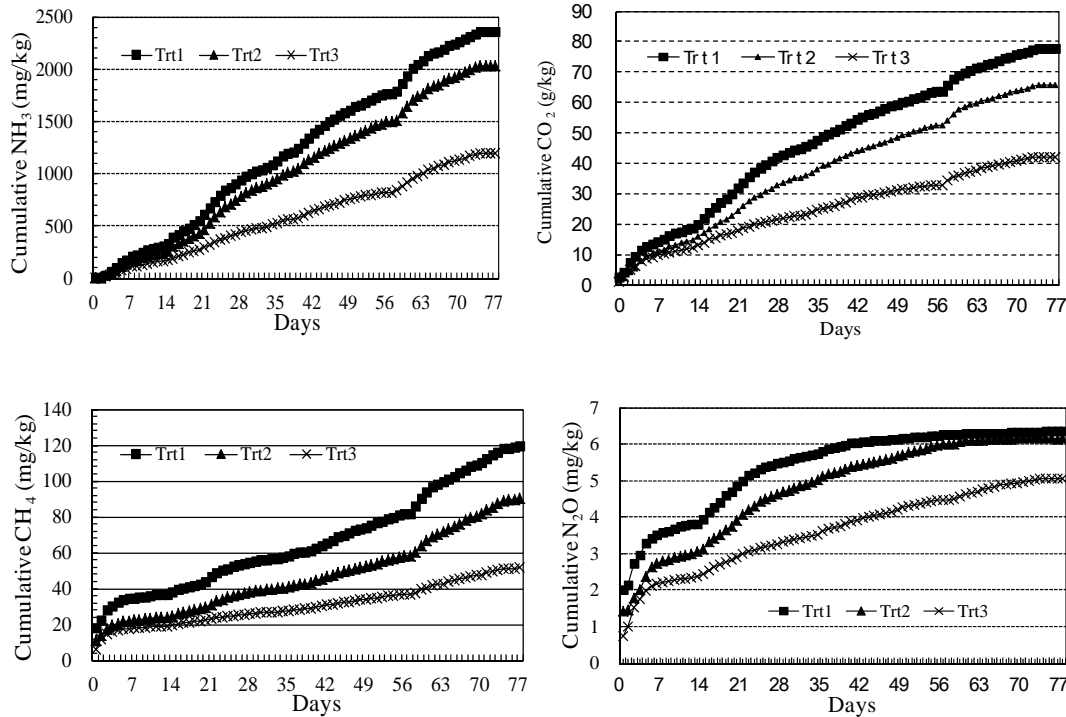


Fig. 4. Cumulative gases emissions of NH<sub>3</sub> (a), CO<sub>2</sub> (b), CH<sub>4</sub> (c) and N<sub>2</sub>O (d) under VR of 0.9, 0.7 or 0.5 m<sup>3</sup>/hr/bin (Trt1, Trt2, and Trt3) from co-composting of dead hens with manure+cornstalk undergoing intermittent mechanical aeration.

## Conclusion

Ammonia (NH<sub>3</sub>) and greenhouse gases (GHG – CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O) emissions from co-composting of laying-hen mortality with manure and cornstalk at different forced aeration or ventilation rate (VR) were characterized over an 11-wk period. NH<sub>3</sub> emission rate remained relatively stable when the compost material was at a high temperature. Sharp increase in CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emissions occurred immediately after composting material was built. The VR regimens were found to have significant impact on the emissions of NH<sub>3</sub>, CO<sub>2</sub> and CH<sub>4</sub>, with higher VR leading to higher emissions.

The present study showed that co-composting poultry mortalities with manure and cornstalk was possible using forced aeration compost bin system. It also showed that it is possible to reduce GHG emissions by manipulating VR through the compost piles while achieving the

desired final compost product. In this study an VR of 0.7 m<sup>3</sup>/hr/bin was found to be superior to VR of 0.5 m<sup>3</sup>/hr/bin or 0.9 m<sup>3</sup>/hr/bin.

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### **References**

- Ahn H., T. Richard, H. Choi. 2007. Mass and thermal balance during composting of poultry manure—Wood shavings mixture at different aeration rates. *Process Biochem.* 42, 215-233.
- Ahn H., W. Mulbry, J. White, S. Kondrad. 2011. Pile mixing increases greenhouse gas emissions during composting of dairy manure. *Bioresour. Technol.* 102, 2904-2909.
- Fukumoto Y., T. Osada, D. Hanjima, K. Haga. 2003. Patterns and quantities of NH<sub>3</sub>, N<sub>2</sub>O and CH<sub>4</sub> emissions during swine manure composting without forced aeration-effect of compost pile scale. *Bioresour. Technol.* 89, 109-114.
- Hanajima D., K. Kuroda, K. Morishita, J. Fujita, K. Maeda, R. Morioka. 2010. Key odor components responsible for the impact on olfactory sense during swine feces composting. *Bioresour. Technol.* 101, 2306-2310.
- Hao X., K. Stanford, T. McAllister, F. Larney, S. Xu. 2009. Greenhouse gas emissions and final compost properties from co-composting bovine specified risk material and mortalities with manure. *Nutr. Cycl. Agroecosyst.* 83, 289-299.
- Kader N., P. Robin, J. Paollat, P. Leterme. 2007. Turning, compacting and the addition of water as factors affecting gaseous emissions in farm manure composting. *Bioresour. Technol.* 98, 2619-2628
- Kuroda K., T. Osada, M. Yonaga, A. Kanematu, T. Nitta, S. Mouri, T. Kojima. 1996. Emissions of malodorous compounds and greenhouse gases from composting swine feces. *Bioresour. Technol.* 56, 265-271.
- Li X., R. Zhang, Y. Pang. 2008. Characteristics of dairy manure composting with rice straw. *Bioresour. Technol.* 99, 359-367.
- Matsumura H., M. Sasaki. S. Kato, K. Nakasaki. 2010. Unusual effects of triacylglycerol on the reduction of ammonia gas emission during thermophilic composting. *Bioresour. Technol.* 101, 2300-2305
- NY525-2002. China national standards for organic fertilizers. Ministry of Agriculture of the People's Republic of China, 2002-08-27, Beijing, China.
- Pagans E., R. Barrena, X. Font, A. Sanchez. 2006. Ammonia emissions from the composting of different organic wastes. Dependency on process temperature. *Chemosphere.* 62, 1534– 1542.
- Sivakumar K., V. Kumar, P. Jagatheesan, K. Viswanathan, D. Chandrasekaran. 2008. Seasonal variations in composting process of dead poultry birds. *Bioresour. Technol.* 99, 3708-3713
- Szanto G. H. Hamelers, W. Rulkens, A. Veeken. 2007. NH<sub>3</sub>, N<sub>2</sub>O and CH<sub>4</sub> emissions during passively aerated composting of straw-rich pig manure. *Bioresour. Technol.* 98, 2659-2670
- Tamura T., T. Osada. 2006. Effect of moisture control in pile-type composting of dairy manure by adding wheat straw on greenhouse gas emission. *Int Congr.* 1293, 311-314

- The People's republic of China initial national communications on climate change, 2004. Beijing: China Planning Press, 15 - 20.
- Xu S., X. Hao, K. Stanford, T. McAllister, F. Larney, J. Wang. 2007. Greenhouse gas emissions during co-composting of cattle mortalities with manure. *Nutr. Cycl. Agroecosyst.* 78, 177-187.
- Xu W., T. Reuter, Y. Xu, Y. Hsu, K. Stanford, T. McAllister. 2011. Field scale evaluation of bovine-specific DNA as an indicator of tissue degradation during cattle mortality composting . *Bioresour. Technol.* 102, 4800-4806.
- Yasuda T., K. Kuroda, Y. Fukumoto, D. Hanajima, K. Suzuki. 2009. Evaluation of full-scale biofilter with rockwool mixture treating ammonia gas from livestock manure composting. *Bioresour. Technol.* 100, 1568-1572.