AMMONIA AND GREENHOUSE GAS EMISSIONS FROM CO-COMPOSTING OF DEAD HENS WITH MANURE AS AFFECTED BY FORCED AERATION RATE

Z. Zhu, H. Dong, J. Xi, H. Xin

ABSTRACT. *The effect of ventilation rate (VR) on ammonia and greenhouse gas emissions from co-composting dead hens mixed with hen manure was quantified. Three VR levels of 0.9, 0.7, and 0.5* m^3 h^{-1} *were evaluated. Gaseous concentrations were measured using a multi-gas infrared photoacoustic analyzer, VR was measured with flowmeters, and the gas emission rate was computed from the VR and gas concentration. Decomposition of the carcasses over the 11-week composting period was greater than 88%. VR was found to significantly affect* NH_3*,* CO_2*, and* CH_4 *emissions (*$p < 0.05$*). Specifically, cumulative emissions per kg of initial matter for VR of 0.9, 0.7, and 0.5* m^3 h^{-1} *were, respectively, 2.4, 2.0, and 1.2 g* NH_3*; 78, 66, and 42 g* CO_2*; 120, 90, and 52 mg* CH_4*; and 6.4, 6.1, and 5.1 mg* N_2O*. Hence, the study results suggest that the ventilation rate can be adjusted to reduce* NH_3 *and GHG emissions from animal mortality compositing.*

Keywords. *Composting, Dead hens, Greenhouse gas,* NH_3*, Ventilation rate.*

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 has been reported in the literature (Sivakumar et al., 2008; Xu et al., 2007; Xu et al., 2011; Hao et al., 2009), and the results showed that co-composting of dead poultry and other waste with manure was successful under different weather conditions.

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 2860 Gg of methane (CH_4) and 270 Gg of nitrous oxide (N_2O) are emitted from livestock manure management in China, accounting for 6.4% of the total CH_4 and 21.3% of the total N_2O emissions in 2005 (NDRC, 2013). Several factors are involved in composting that could affect the magnitude of the gaseous emissions, such as the scale of the operation, process temperature (Pagans et al., 2006; Matsumura et al., 2010), ventilation or aeration rate (Li et al., 2008; Ahn et al., 2007; Shen et al., 2011), and management and amendments (Tamura and Osada, 2006; Yasuda et al., 2009; Fukumoto et al., 2003; Ahn et al., 2011; Szanto et al., 2007; El Kader et al., 2007). Co-composting livestock mortalities with manure could affect the composting process and the rate of 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 and/or forced ventilation), in addition to the moisture content and C/N ratio of the composting materials, is an important factor influencing NH_3 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 poultry manure and the influence of associated operational parameters on NH_3 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_3 and GHG, and the properties of final compost product. The research results will provide insight toward the 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.

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The authors are **Zhiping Zhu,** Associate Professor, **Hongmin Dong, ASABE Member,** Professor and Deputy Director, and **Jialin Xi,** Graduate Student, Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences, The Key Laboratory of Energy Conservation and Waste Treatment of Agricultural Structures, Ministry of Agriculture, Beijing, China; **Hongwei Xin, ASABE Fellow,** Professor, Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, Iowa. **Corresponding author:** Hongmin Dong, Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences, 12 Zhongguancun South Street, Beijing 100081, China; phone: 86-10-82109979; e-mail: donghm@ieda.org.cn.

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MATERIALS AND METHODS

EXPERIMENTAL DESIGN AND FACILITY

The study was carried out from 9 April to 25 June (late spring to early summer) in a field experiment station at the Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences (IEDA, CAAS) in 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^3 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 and chopped cornstalk mixture, then side-by-side placement of about 15 dead mature hens (~2 kg $bird^{-1}$) in the middle of each compost bin, and finally covered with the manure-cornstalk mixture. The initial compost pile had a height of about 80 cm and weighed about 475 kg for each compost bin.

Forced aeration was applied to the compost piles. Fresh air was introduced into each bin through an air distribution plate, which was a plastic panel with a uniform arrangement of 3 mm diameter vent holes near the bottom of the compost bin. The air moved upward through the compost pile and was exhausted through the top outlet on the bin cover (fig. 1). The bin aeration was provided by a common air pump that was connected to a distribution manifold that divided the main air supply through nine identical flowmeters at three VR levels of 0.9, 0.7, and 0.5 $m^3 h^{-1} bin^{-1}$ (Trt1, Trt2, and Trt3, respectively), with each VR replicated three times. The VR was calculated as oxygen demand, water removal, and heat removal using the method of Wei et al. (2000). The corresponding air exchanges per hour (ACH) for the three VR levels were 0.9, 0.7, and 0.5, respectively. The air supply for each treatment was controlled by a timer to operate at 10 min on and 20 min off cycles. The compost piles were remixed and reconstructed once (on day 58) during the 11-week study. A schematic representation of the experimental setup is shown in figure 1.

GAS SAMPLING SYSTEM

A photoacoustic infrared multi-gas analyzer (model 1412, Innova AirTech Instruments, Ballerup, Denmark) along with a multi-channel sampler (IEDA, CAAS, Beijing, China) was used to successively sample the nine compost bins exhaust outlets and the common air inlet. Before actual measurements, the multi-gas analyzer was checked and calibrated, as needed, using individual CO_2, CH_4, N_2O, and NH_3 standard calibration gases procured from the National Standard Material Center in Beijing. For each of the nine air samplings from the outlets of the composting bins, 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, a total of 1.5 h was required to complete one sampling cycle for all nine composting bins, and in total 16 measurements were taken per day for each bin with a daily cycle during the whole composting period. The fresh air concentration was measured for one half-hour each day using the ninth sampling channel, and the result showed that the fresh air concentration remained constant during the experiment period.

Compost temperature was recorded at 1 h intervals throughout the experiment using portable temperature loggers (Hobo Pro v2 U23, Onset Computer Corp., Bourne, Mass.), with two temperature loggers installed at the level of the dead birds in each bin. Ambient air temperature data were obtained from a Beijing weather station that was lo-

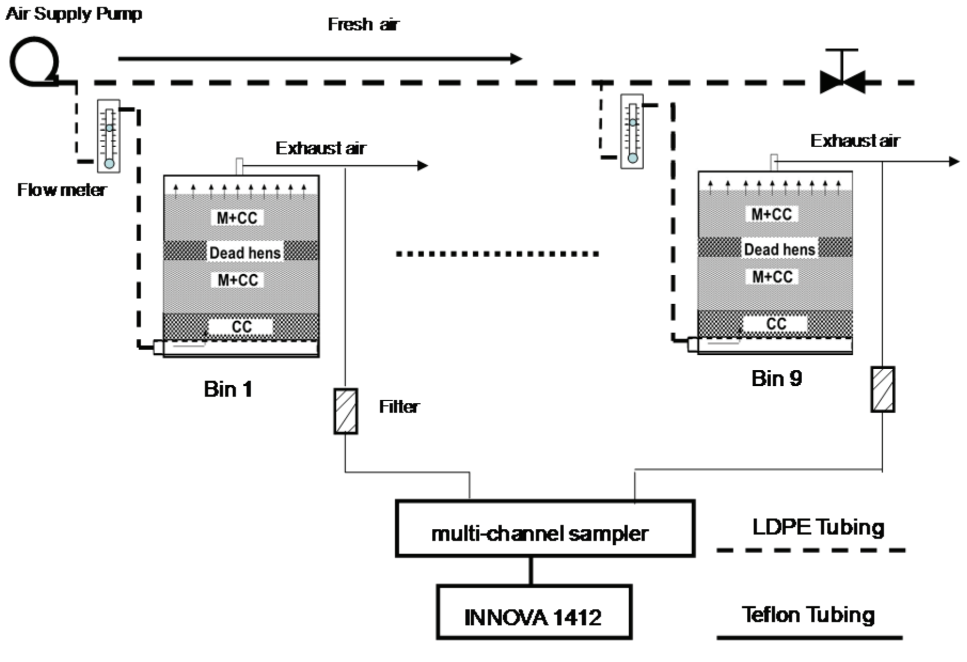


Figure 1. Schematic representation of the composting experimental setup (M = hen manure, CC = chopped cornstalk).

cated about 4 km from the experiment site (China Meteorological Data Sharing Service System).

COMPOST SAMPLE ANALYSIS

Samples of 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 moisture content (MC), organic matter (OM), total carbon (TC), and total nitrogen (TN) at the Animal Environment and Facility Inspection and Testing Center, Ministry of Agriculture, in China. MC and OM content were analyzed according to Chinese national standards (China, 2002). These samples were placed in plastic bags and brought back to the laboratory. The MC was determined gravimetrically by drying subsamples in an oven at 105°C for 24 h. The rest of the samples were oven-dried at 65°C and coarsely ground (<2 mm). The coarse-ground subsamples were further ground (0.150 mm) for total carbon (TC) and total nitrogen (TN) determination in an automated elemental analyzer (PE2400 Series II CHNS System, PerkinElmer, Inc., Waltham, Mass.), while OM was determined with the potassium dichromate method. All analyses were carried out in duplicate, and the values were given as averages of the two samples from each bin.

ESTIMATION OF NH_3 AND GHG EMISSION RATE

The total ammonia and GHG emissions over the composting period were expressed as the mass of each gas per kg of initial material. With the knowledge of airflow rate, gas concentrations of the inlet and outlet air, and initial compost mass, the NH_3 and GHG emission rate (ER) from the compost bins was calculated using the following equation:

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

where ER is the NH_3 or GHG emission rate per kg of initial compost (mg kg^{-1} h^{-1}), C_i and C_o are the NH_3 or GHG mass concentrations of the inlet and outlet air, respectively (mg m^{-3}), Q_{air} is the VR of the compost bin (m^3 h^{-1}), and W is the initial compost mass (kg).

STATISTICAL ANALYSIS

The response variables for different VR regimens were analyzed using Proc GLM in SAS, followed by Duncan's multiple mean comparisons (SAS Institute, Inc., Cary, N.C.) to determine the treatment effect. The results were presented as means ± standard error (SE). A probability of 5% or less was considered significant.

RESULTS AND DISCUSSION

TEMPERATURE CHARACTERISTICS OF COMPOST BINS

Temperature profiles of the composting bins aerated at different ventilation rates are shown in figure 2. At the start of composting, the temperature increased quickly in all bins and peaked at 71.4°C ±0.6°C, 70.6°C ±0.4°C, and 71.5°C ±1.8°C (mean ±SD) on days 4, 5, and 4 for 0.9 (Trt1), 0.7 (Trt2), and 0.5 (Trt3) m^3 h^{-1} bin^{-1}, respectively. The temperature then slowly declined to 60°C by day 18 (Trt1) to day 38 (Trt2). The temperature increased again after remixing but remained above 60°C for only one day and then dropped slowly to 40°C on day 75. Compared to Trt1 (VR of 0.9 m^3 h^{-1} bin^{-1}), Trt2 and Trt3 maintained longer periods of high temperature (>60°C) (38 days for Trt2, and 31 days for Trt3). The shorter period of high temperature with the higher VR of Trt1 presumably arose from the excessive airflow, which caused excessive heat loss from the Trt1 bins as well as greater drying of the bins, as compared to the other two treatments, reducing bacterial activity. Li et al. (2008) reported a similar trend for dairy manure composting with rice straw under different aeration rates.

MANURE AND COMPOST PROPERTIES

The compost properties at the start and end of the 11-week composting period under different VR regimens are presented in table 1. The data show that means values of the compost parameters (final weight, MC, OM, TC, and TN content) were lowest to highest for Trt1 to Trt3, but they were mostly statistically similar for the three VR regimens. One exception was the amount of carcass residuals for Trt3 (0.5 m^3 h^{-1} bin^{-1}). It was significantly higher as compared to those for Trt1 and Trt2, although all the three treatments had a decomposition rate of >88% (88.1% for

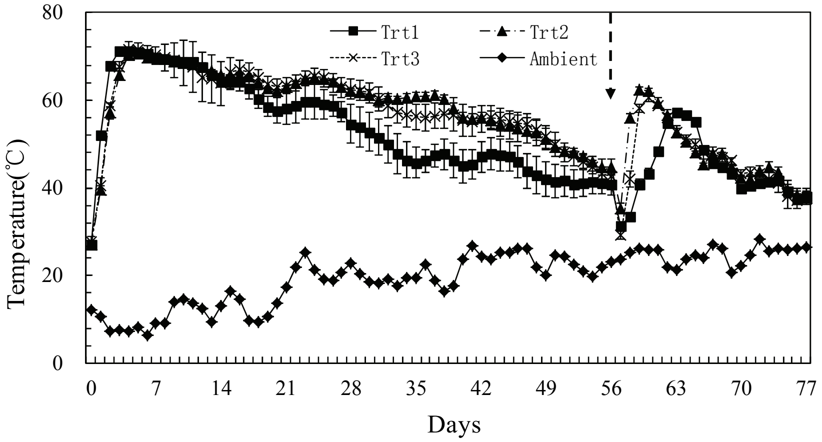


Figure 2. Effect of ventilation rate (VR) on compost temperature measured at the level of dead birds in the composting bins (VR = 0.9, 0.7, and 0.5 m^3 h^{-1} bin^{-1} for Trt1, Trt2 and Trt3, respectively). The vertical arrow indicates remixing of the compost piles.

Table 1. Characteristics of the initial and final compost materials with different ventilation rates (VR) through a 1 m^3 compost bin ($n = 3$).[a]

	Treatment	VR (m^3 h^{-1})	Compost Material (kg bin^{-1})	Dead Hens (kg bin^{-1})	Moisture Content (% w.b.)	Organic Matter (% d.b.)	Total Carbon (% d.b.)	Total Nitrogen (% d.b.)
Cornstalk	-	-	-	-	9.54 ±0.14	77.2 ±0.1	43.7 ±0.3	1.08 ±0.06
Manure	-	-	-	-	67.6 ±1.8	46.3 ±1.2	28.1 ±0.2	4.56 ±0.08
Initial Stage	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	28.2 ±0.3	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 Stage[b]	Trt1	0.9	234 ±12.4 a	2.7 ±0.1 a	57.6 ±0.3 a	40.3 ±2.2 a	24.1 ±0.6 a	2.05 ±0.02 a
	Trt2	0.7	255 ±26.3 a	2.8 ±0.2 a	58.4 ±0.8 a	42.2 ±0.7 a	24.6 ±0.3 a	2.12 ±0.07 a
	Trt3	0.5	265 ±7.5 a	3.4 ±0.2 b	59.4 ±0.6 a	45.0 ±0.5 a	25.4 ±1.1 a	2.11 ±0.07 a

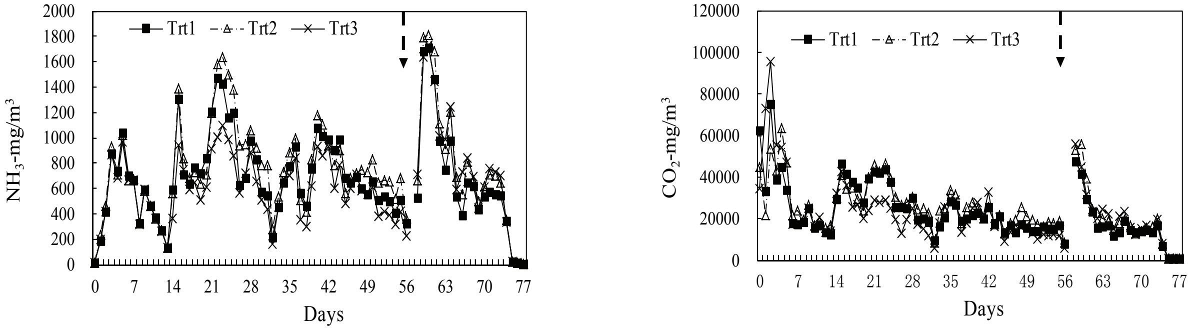
[a] Values are means ±SE; w.b. = wet basis; d.b. = dry basis.

[b] Means in the same column followed by different letters are significantly different ($p < 0.05$).

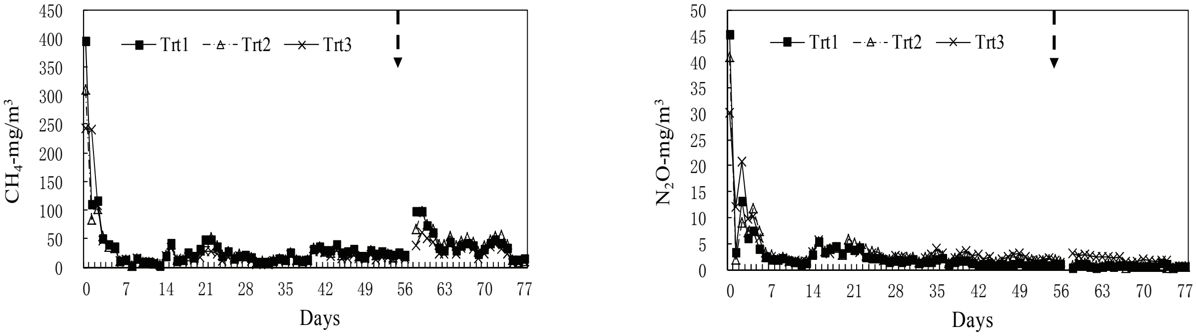
Trt3, 90.2% for Trt2, and 90.4% for Trt1), as assessed by reduction in carcass weight. Approximately 38.6% to 43.4% of the initial dry matter weight and 52.1% to 53.4% of the initial TN were lost during composting. These values were higher than those reported by Fukumoto et al. (2003), who reported that DM decreased by about 32.4% to 35.8% and TN decreased by about 39.5% to 42.5% for swine manure composting without forced aeration. At the end of the composting period, it was observed that 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 may be due to insufficient aeration. Composting requires oxygen for aerobic activity, and excessively low aeration would lead to anaerobic conditions. However, too much aeration would lead to excessive cooling, preventing the thermophilic conditions required for the optimum rate of decomposition. Between these two extremes is an optimum aeration rate that provides sufficient oxygen for aerobic decomposition while keeping the temperature in the thermophilic range (Ahn et al., 2007). For the experimental conditions of this study, the results suggest that the middle VR value (0.7 m^3 h^{-1}) (Trt2) was most suitable for forced aeration composting, having higher carcass decomposition, TC, and TN content at the end of the composting period as compared with Trt1 and Trt3 (table 1).

PATTERNS OF GASEOUS EMISSIONS

Ammonia concentration in the exhaust air fluctuated over time and remained quite high during the period of high temperature of the composting material in all regimens (fig. 3a). The NH_3 emission patterns observed in this study agreed with that reported by Fukumoto et al. (2003), in which swine manure was composted without forced aeration. NH_3 emissions slowly decreased before remixing, suggesting that NH_3 emissions from deep within the compost were prevented until this material was redistributed to the top of the pile. The NH_3 concentration increased again



(a) NH_3 **(b) CO_2**



(c) CH_4 **(d) N_2O**

Figure 3. Exhaust air concentrations of (a) NH_3, (b) CO_2, (c) CH_4, and (d) N_2O with VR of 0.9 (Trt1), 0.7 (Trt2), or 0.5 (Trt3) m^3 h^{-1} bin^{-1} during the mechanically aerated composting experiment. Vertical arrows indicate remixing of the compost piles.

after remixing and then quickly decreased to lower levels. After 11 weeks of composting, NH_3 emissions almost ceased in all treatments due to the remaining ammonium nitrogen in the compost becoming stable.

The CO_2 emissions in the exhaust air for the three VR regimens resembled that reported by Ahn et al. (2011) and Hao et al. (2009), who reported that pile mixing increased gas emissions during composting. The CO_2 concentration from the compost bins peaked within two to four days after construction of the compost pile and gradually decreased (fig. 3b). The CO_2 concentration reached another peak after remixing and then quickly decreased. The CO_2 emission patterns were similar for all three VR regimens due to the same management procedure (except for different aeration rates).

The CH_4 emissions in the exhaust air for the three VR regimens at the beginning period resembled those reported by Fukumoto et al. (2003) and Ahn et al. (2011), who reported that CH_4 increased after remixing compost without forced aeration. In this study, the CH_4 emissions from the compost bins peaked shortly after construction of the piles, and then quickly decreased and remained low until remixing (fig. 3c). The CH_4 emissions increased again after remixing and quickly decreased to low levels. We speculate that the central region of the compost pile was under anaerobic conditions due to lack of oxygen in the beginning, and hence produced more CH_4. With the supply of fresh air into the bins, the conditions became more aerobic, and hence reduced CH_4 generation. CH_4 emission patterns were similar for all three VR regimens.

The N_2O emissions from the compost bins peaked right after construction of the piles and quickly decreased to the ambient level (fig. 3d). Remixing had no impact on N_2O concentration. This result did not resemble the patterns reported by Fukumoto et al. (2003) and Ahn et al. (2011), who observed that most N_2O emissions occurred during the late composting period. This difference could possibly be attributed to the difference in the microenvironment within the pile, which was likely more aerobic in this 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.

EFFECT OF VR ON GHG AND NH_3 EMISSIONS

The cumulative CO_2, CH_4, and NH_3 emissions over the 11-week composting period were significantly affected by VR ($p < 0.05$), although cumulative N_2O was not ($p = 0.22$ to 0.84) (table 2). The mean cumulative emissions per kg of initial matter for VR of 0.9, 0.7, and 0.5 m^3 h^{-1} were, respectively, 2.4, 2.0, and 1.2 g NH_3; 78, 66, and 42 g CO_2; 120, 90, and 52 mg CH_4; and 6.4, 6.1, and 5.1 mg N_2O. Higher VR led to higher cumulative gaseous emissions when higher VR could promote the composting process. The results showed that the VR of 0.7 m^3 h^{-1} bin^{-1} could reduce gaseous emission with a higher decomposition rate as compared to VR of 0.9 m^3 h^{-1} bin^{-1}. Hence, keeping the VR as low as possible while achieving good composting conditions would be conducive to saving energy and reducing gaseous emissions. The cumulative gaseous emissions during the composting period are shown in figure 4, while the gaseous emissions during different time intervals of the composting period are given in table 3. Higher emissions were found during the first four weeks for CO_2 (49.8% to 53.9%), CH_4 (43.1% to 50.6%), and N_2O (66.8% to 86.2%). The higher emissions presumably arose from lower oxygen in the compost piles at the start. NH_3 emissions remained quite constant throughout the whole composting period (fig. 4a).

Table 2. Effect of ventilation rate (VR) on cumulative GHG and NH_3 emissions during 11-week co-composting of dead hens with hen manure, expressed as amount per kg of initial compost material.[a]

VR (m^3 h^{-1} bin^{-1})	CO_2 (g kg^{-1})	CH_4 (mg kg^{-1})	N_2O (mg kg^{-1})	GHG (g CO_2-eq kg^{-1})[b]	NH_3 (g kg^{-1})
0.9	78 a ±0.8	120 a ±7.7	6.4 a ±0.6	82 a ±0.6	2.4 a ±0.08
0.7	66 b ±1.7	90 b ±11.3	6.1 a ±0.5	70 b ±2.2	2.0 b ±0.03
0.5	42 c ±2.2	52 c ±2.9	5.1 a ±0.8	45 c ±2.4	1.20 c ±0.06

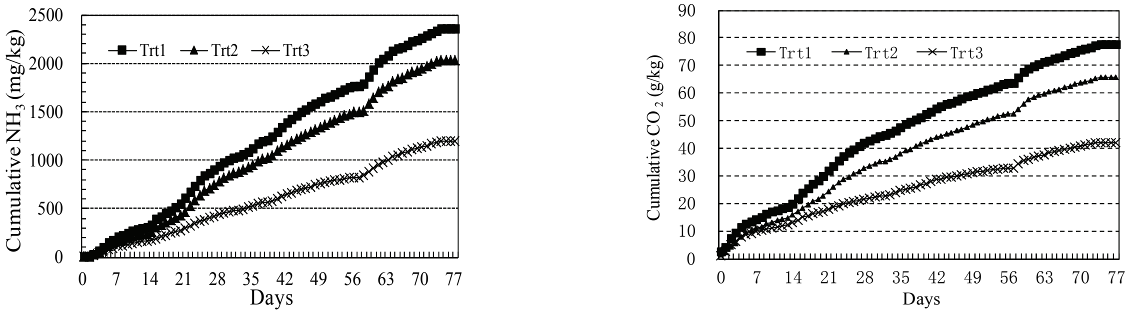
[a] The cumulative gas emission is based on initial fresh composting material. Values are means ± SE of three replicate bins. Means followed different letters are significantly different ($p < 0.05$).

[b] GWP of 21 for CH_4 and 310 for N_2O.

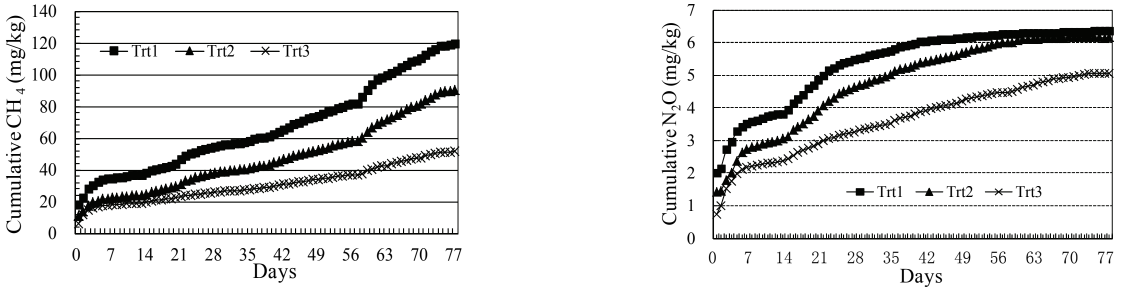
The CO_2 emissions accounted for about 99.6% of total C loss, while the CH_4 emissions accounted for about 0.4% of total C loss (table 3). The contribution of CH_4 emissions to total C loss was much lower than the 3.1% to 3.9% reported by Xu et al. (2007), who reported GHG emissions from co-composting of cattle mortalities with manure using a windrow method. The difference presumably resulted from the different composting methods involved, i.e., forced aeration (current study) versus static piles (Xu et al., 2007). The CO_2 emissions accounted for 10.1% to 18.6% of initial TC, which was higher than the values reported for static pile composting (Hao et al., 2009). The NH_3 emissions accounted for about 99.8% of total N loss, whereas the N_2O emissions accounted for about 0.2% of total N loss (table 3).

SUMMARY AND CONCLUSIONS

Ammonia and GHG (CO_2, CH_4, and N_2O) emissions from co-composting of laying-hen mortality with manure and cornstalk at different forced ventilation rates (VR) were characterized over an 11-week period. The VR regimens were found to have significant impact on the emissions of NH_3, CO_2, and CH_4, with higher VR leading to higher emissions. Specifically, cumulative emissions per kg of initial matter for VR of 0.9, 0.7, and 0.5 m^3 h^{-1} were, respectively, 2.4, 2.0, and 1.2 g NH_3; 78, 66, and 42 g CO_2; 120, 90, and 52 mg CH_4; and 6.4, 6.1, and 5.1 mg N_2O. This study showed that it is possible to reduce GHG emissions by manipulating the VR through the compost piles while achieving the desired final compost product. In this study, a VR of 0.7 m^3 h^{-1} bin^{-1} was found to be superior to VR of 0.5 or 0.9 m^3 h^{-1} bin^{-1}. However, this experiment used a very narrow range of aeration rates and presents results from only one season. Future work will need to vary the VR more widely and include different weather conditions.



(a) NH_3 **(b) CO_2**



(c) CH_4 **(d) N_2O**

Figure 4. Cumulative gaseous emissions of (a) NH_3, (b) CO_2, (c) CH_4, and (d) N_2O with VR of 0.9 (Trt1), 0.7 (Trt2), or 0.5 (Trt3) m^3 h^{-1} bin^{-1} from co-composting of dead hens with manure and cornstalk during the mechanically aerated composting experiment.

Table 3. GHG and NH_3 emissions from dead hen and manure composting bins with different forced ventilation rates.[a]

	Percentages of Total Emissions (%)											
	CO_2-C			CH_4-C			NH_3-N			N_2O-N		
	Trt1	Trt2	Trt3	Trt1	Trt2	Trt3	Trt1	Trt2	Trt3	Trt1	Trt2	Trt3
Days 0 to 14	25.7 ±2.5	24.1 ±0.3	31.0 ±2.0	31.6 ±8.0	28.2 ±3.3	38.1 ±1.8	14.1 ±0.6	12.6 ±0.3	14.4 ±1.2	60.8 ±8.1	50.5 ±6.4	48.7 ±5.9
Days 15 to 28	28.2 ±1.6	25.7 ±1.9	20.8 ±3.5	14.2 ±2.6	15.0 ±3.0	12.5 ±1.9	26.0 ±1.3	26.0 ±1.4	22.8 ±3.1	25.4 ±4.5	25.4 ±4.3	18.1 ±4.1
Days 29 to 42	16.1 ±0.9	17.3 ±1.9	16.2 ±2.7	9.2 ±1.2	9.6 ±1.2	9.1 ±0.3	18.6 ±1.2	18.6 ±2.2	17.3 ±1.0	8.7 ±1.7	12.3 ±2.0	12.7 ±2.6
Days 43 to 57	11.8 ±1.5	12.9 ±1.5	10.2 ±3.3	13.6 ±1.6	12.8 ±1.2	11.7 ±1.1	16.1 ±1.3	16.2 ±2.0	14.4 ±2.7	3.3 ±1.2	9.1 ±3.0	9.3 ±2.4
Days 58 to 77	18.2 ±1.0	20.0 ±0.8	21.7 ±1.4	31.4 ±4.4	34.5 ±4.6	28.6 ±0.9	25.3 ±1.3	26.5 ±2.0	31.2 ±0.4	1.7 ±1.0	2.6 ±1.6	11.2 ±2.6
Total emissions (kg)[b]	10.1 a ±0.1	8.5 b ±0.2	5.5 c ±0.3	0.04 a ±0.003	0.03 b ±0.004	0.02 c ±0.001	0.92 a ±0.03	0.79 b ±0.01	0.47 c ±0.02	1.92 a ±0.2	1.86 a ±0.2	1.53 a ±0.2

[a] Trt1 = 0.9, Trt2 = 0.7, and Trt3 = 0.5 m^3 h^{-1} bin^{-1}. Values are means ± SE of three replicate bins.

[b] Means followed by different letters are significantly different ($p < 0.05$). N_2O total emissions are in units of g.

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