Ammonia Emissions from a Commercial Poultry Manure Composting Facility

Lingying Zhao
Ohio State University

Roderick B. Manuzon
Ohio State University

Matthew J. Darr
Iowa State University, darr@iastate.edu

Harold M. Keener
Ohio State University

Albert J. Heber
Purdue University

See next page for additional authors

Follow this and additional works at: http://lib.dr.iastate.edu/abe_eng_conf

Part of the Agriculture Commons, and the Bioresource and Agricultural Engineering Commons

The complete bibliographic information for this item can be found at http://lib.dr.iastate.edu/abe_eng_conf/286. For information on how to cite this item, please visit http://lib.dr.iastate.edu/howtocite.html.
Ammonia Emissions from a Commercial Poultry Manure Composting Facility

Abstract
Composting is an effective waste management technology for converting animal wastes into valuable organic fertilizer. However, air emissions from composting, especially ammonia (NH₃) emission, reduces the nitrogen fertilizer value of the compost and greatly impacts the environment. Ammonia emission from commercial composting facilities is not well understood and is limiting mitigation or recovery of NH₃ emission from these facilities. The goal of this study was to determine the NH₃ emission from a poultry manure compost facility and its temporal variations for development of mitigation strategies. A commercial composting facility was chosen for this study. Manure was supplied from four adjacent manure-belt layer barns. The composting building was tunnel ventilated by four 122-cm exhaust fans. Ammonia concentration at the building inlet and the fan exhausts was monitored quasi-continuously for one month in each of the four seasons using a MSA photoacoustic NH₃ analyzer. Air temperature and humidity at the exhausts were monitored using a HOBO temperature and RH sensor and data logger. The exhaust fans were calibrated using FANS units to quantify the ventilation rate of the building. Ammonia emission rate was calculated according to the NH₃ concentrations and building ventilation rate. The daily average NH₃ concentrations at the exhaust of the compost house varied from 123 ppm in spring to 167 ppm in summer. The daily average NH₃ emission rates of the compost facility varied from 231 kg/d in spring to 315 kg/d in summer. Strong diurnal variations exist in spring and summer seasons. Daytime NH₃ emission is significantly higher than that of nighttime. The annual NH₃ emission rate of the composting facility was estimated as 96,143 kg. The emission factors were calculated as 13±1.3 kg/ton · d and 0.32 ±0.14 g/d · hen. The results of this study will contribute to the development of NH₃ emission mitigation technologies and management practices.

Keywords
Ammonia emission, Composting facility, Nitrogen balance, Temporal variations, Nitrogen loss

Disciplines
Agriculture | Bioresource and Agricultural Engineering

Comments

Authors
Lingying Zhao, Roderick B. Manuzon, Matthew J. Darr, Harold M. Keener, Albert J. Heber, and Ji-Qin Ni

This conference proceeding is available at Iowa State University Digital Repository: http://lib.dr.iastate.edu/abe_eng_conf/286
Ammonia Emissions from a Commercial Poultry Manure Composting Facility

L. Y. Zhao1, R. Manuzon1, M. Darr2, H. Keener1, A. J. Heber3, and J.-Q. Ni3
1 Department of Food, Agricultural and Biological Engineering, The Ohio State University, Columbus, OH
2 Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA
3 Department of Agricultural & Biological Engineering, Purdue University, West Lafayette, IN

Abstract. Composting is an effective waste management technology for converting animal wastes into valuable organic fertilizer. However, air emissions from composting, especially ammonia (NH3) emission, reduces the nitrogen fertilizer value of the compost and greatly impacts the environment. Ammonia emission from commercial composting facilities is not well understood and is limiting mitigation or recovery of NH3 emission from these facilities. The goal of this study was to determine the NH3 emission from a poultry manure compost facility and its temporal variations for development of mitigation strategies. A commercial composting facility was chosen for this study. Manure was supplied from four adjacent manure-belt layer barns. The composting building was tunnel ventilated by four 122-cm exhaust fans. Ammonia concentration at the building inlet and the fan exhausts was monitored quasi-continuously for one month in each of the four seasons using a MS4 photoacoustic NH3 analyzer. Air temperature and humidity at the exhausts were monitored using a HOBO temperature and RH sensor and data logger. The exhaust fans were calibrated using FANS units to quantify the ventilation rate of the building. Ammonia emission rate was calculated according to the NH3 concentrations and building ventilation rate. The daily average NH3 concentrations at the exhaust of the compost house varied from 123 ppm in spring to 167 ppm in summer. The daily average NH3 emission rates of the compost facility varied from 231 kg/d in spring to 315 kg/d in summer. Strong diurnal variations exist in spring and summer seasons. Daytime NH3 emission is significantly higher than that of nighttime. The annual NH3 emission rate of the composting facility was estimated as 96,143 kg. The emission factors were calculated as 13±1.3 kg/ton ·d and 0.32 ±0.14 g/d ·hen. The results of this study will contribute to the development of NH3 emission mitigation technologies and management practices.

Keywords. Ammonia emission, Composting facility, Nitrogen balance, Temporal variations, Nitrogen loss

Introduction

Ammonia (NH3) emission has become a significant environmental and public concern as it impacts health, ecosystem acidity, and formation of small aerosol particles (PM2.5) (NRC, 2003). It is estimated by the EPA National Emission Inventory that animal production and other agricultural activities contribute 80.9% of NH3 emissions to the atmosphere, which was about 2,418,595 tons in 2002 (USEPA, 2004). It is urgently needed to understand NH3 emission from agricultural sources and develop innovative technologies for the abatement and recovery of NH3 emissions to protect the environment and conserve nitrogen of animal manure in today’s high fertilizer cost environment.

Composting of manure is one of the most attractive waste management technologies for converting animal wastes into organic fertilizer because its uses minimize utilization of inorganic fertilizer and contribute to the organic carbon bank in the soils (Pitaway, 2002). Unlike manure, compost fertilizers are more stable and can be stored or applied to soil with little or no odor, pathogen, weed, or fly breeding potential (Hao et al., 2001). In poultry layer industry, more and more traditional deep-pit houses are built or retrofitted to manure-belt houses with separate manure storage or composting buildings. The United States Environmental Protection Agency estimated bio-solids generation to increase from 6.9 to 8.2 million tons from 1998 to 2010 (USEPA, 1999). However, composting processes may result in significant air emissions, especially NH3 emission. There is a lack of knowledge on air emission rates from manure composting operations. These emissions not only reduce the agronomic value of the compost, but also greatly impact the environment with the release of harmful gases like ammonia (NH3), Nitrous oxide (N2O), and methane (CH4), of which NH3 loss has the highest economic impact because of its value as a fertilizer.

Limited laboratory studies measured NH3 emissions from composting processes. Matsusada et al. (2002) have shown that NH3 emissions from composting animal manure varied from 323 mg/kg to 2840 mg/kg for swine manure, from 41 mg/kg to 458 mg/kg for dairy manure, and from 15 mg/kg to 2740 mg/kg for poultry manure for aeration rates ranging from 0.2 to 1.4 L/(min kg) and C/N ratios from 13 to 43 for swine, 19 to 42 for dairy, and 19 to 56 for poultry, respectively. Hao et al. (2001) documented that, as high as 41.6% of the total nitrogen is lost during the composting of straw bedded manure from cattle feedlot manure composting. The mean values of the total NH3 emission per composting period was 57.6 g/m2. Most
of the NH₃ emissions occur within the initial three weeks of the composting period while the peak of N₂O emissions occur in the middle of the composting period (Hellebrand and Kalk, 2001).

The important factors that affect NH₃ emissions during manure composting include temperature, pH, initial nitrogen content of the manure substrate, aeration, and the composting process. According to Pagans et al. (2006), ammonia emissions increased exponentially during the thermophilic first stage (≥45°C) and linearly within the mesophilic final stage (25°C to 40°C) of composting. High pH (>7) and aeration rate increases NH₃ volatilization, while high C/N ratio decreases it (Matsuda et al., 2002). Hellebrand and Kalk (2001) reported that there was an interaction between aeration rate and C/N ratio on the type of nitrogen transformations. High aeration rate and low carbon content result in nitrite accumulation and incomplete ammonium oxidation which leads to high NH₃ emissions.

Keener et al. (2002) studied ammonia emission from the same composting facilities using a mass-balance approach and concluded the ammonia emission from manure belt layer buildings and the composting facility was 0.15-0.16 kg per hen per yr. A simple measurement of ammonia emission was conducted and the measurement results did not compare well with the mass-balance estimation results.

Existing literatures show significant variations in NH₃ emission from composting facilities due to difference in facility types and management practices. For accurate estimate of NH₃ emission, long-term field study of commercial composting facilities can directly supply valuable NH₃ emission data. A simple method to estimate NH₃ emission through composting process is also need for better management of composting processes for reduced NH₃ emission. The specific objectives of this study were to (1) measure NH₃ emission rates from a composting facility and (2) determine the diurnal and seasonal variations of NH₃ emission.

**Materials and Methods**

**The Composting Facilities**

A poultry manure compost facility with covered hoop structures and mechanical ventilation was used for this study. The composting facility consists of two buildings receiving poultry manure from four adjacent manure-belt layer barns housing 1 million laying hens. The compost buildings are 12 lanes (108 m long and 64 m wide) and 6 lanes (108 m long and 32 m wide) with eight and four 122-cm exhaust fans, respectively (Figure 1). Manure is composted, using Salmet composters, into a dry product suitable for fertilizer applications. The Salmet composter tuning machines were used to turn the compost windrows row by row every day from 8:00 a.m. to 5:00 p.m. Three rows of compost windrow were turned in each day. The poultry manure is moved 6.1 m (20 ft) every 3 days and exits the composting lanes after 54 days after being fully composted. The air inlets to the building are located at the storage end of the building and the exhaust fans are located at the other end of the composting building. This layout results in a tunnel ventilated composting facility.

![Figure 1. Layout of the layer barns and composting facilities.](image-url)
Measurement Plan and Methods

To determine NH₃ emission, the NH₃ concentrations at the air inlet and exhaust ends of one of the composting facilities (Figure 2) were measured continuously for one month in each season: Spring, Summer, Fall, and Winter. Ventilation rates of the composting buildings were quantified by measuring the building static pressure and fan performance. The continuous one-month measurements in four seasons were to reveal daily and seasonal variations in NH₃ emission from the composting facility.

![Measurement plan and detailed layout of the composting facility](image)

The schematic of the sampling system is shown in Figure 3. The air samples was drawn using a Teflon gas sampling line and a gas sampling probe located in front of one of the four 122-cm axial exhaust fans. Ammonia concentration, temperature, and relative humidity were simultaneously measured at the exhaust of the composting facility. Ammonia concentration was measured using a photoacoustic NH₃ analyzer (MSA Chilgard RT, MSA Inc., Pittsburg, PA) together with solenoids and data loggers. An HOBO RH/temp sensor and data logger (U23 Temperature/RH data logger, Onset Computer Corp, Pocasset, MA) was used to monitor air temperature and relative humidity at the NH₃ sampling location. A digital manometer was used to measure the differential static pressure of the composting facility.

Particulate filters were installed at both ends of the Teflon sampling line to prevent contamination of the NH₃ sensor. The MAS NH₃ analyzer was calibrated for NH₃ with an accuracy of ± 1 ppmv. It drew air samples at a flow rate of 0.75 liter/min and responds 90% in 70 seconds to a sample concentration step change. To stand for the high erosion environment and varied ambient weather conditions, The NH₃ analyzer was housed in a NEMA 4 enclosure ventilated using fans with automatic control to achieve a workable environment for the analyzer. The sampling lines were heated using heat tape and insulated with pipe insulation materials to prevent condensation inside the sampling tubes. Ammonia concentration was recorded using data loggers (U12 data logger, Onset Computer Corp, Pocasset, MA) via the 4-20 mA signal output of the NH₃ analyzer. Data was acquired quasi-continuously at 2-minute intervals.
Quantification of Ventilation Airflow Rates

A portable fan tester (FANS) (Gates et al., 2002) was used to determine the actual fan performance curves. The FANS was calibrated at the University of Illinois BESS lab, thus it was very accurate field-based reference measurement technique to quantify fan airflow. Building static pressure was used to calculate airflow rate of each fan and the ventilation rate of the composting facilities was calculated as summation of airflow rate of each operating fan (Eq. 1). Airflow was expressed in terms of volume of dry air at standard conditions (20°C and 1 atm).

\[ Q = \sum_{i} Q_i \]  

where \( Q \) is the ventilation rates of the composting facility and \( Q_i \) is the airflow rate of the \( i \)th individual exhaust fan.

Emission Rate Determination

The concentrations, \( C \), of the samples were converted to emission rates, \( E \), by the application of a simple continuity equation as follows:

\[ E = Q(C_{\text{out}} - C_{\text{in}}) \]  

where \( C_{\text{out}} \) is NH3 concentration at the air exhausts; \( C_{\text{in}} \) is NH3 concentration at the air inlet. Application of this equation assumes complete mixing of NH3 before it is emitted from the composting building.

Data Processing and Analysis

Data collected was analyzed by general descriptive statistical analysis. The association between NH3 emission and weather conditions was evaluated using statistical regression and correlation analysis. The means of NH3 concentrations and emissions at each season were compared using t-test at 95% significance interval.

Results and Discussions

Weather Conditions

Table 1 summarizes the weather conditions near the composting facility during the test periods in May, August, October, and January. The measurement periods represented weather conditions in four typical seasons, Spring, Summer, Fall, and Winter. The ambient temperatures ranged from -20°C to 35°C (-4°F to 95°F) and ambient relative humidity ranged from 64-78%. The average ambient temperatures in Spring, Summer, Fall, and Winter were 19°C (67°F), 23°C (73°F), 17°C (62°F), and -3°C (27°F), respectively.

<table>
<thead>
<tr>
<th>Sampling Event</th>
<th>Temp (°C) Ave. ± std.</th>
<th>Maximum Temp (°C)</th>
<th>Minimum Temp (°C)</th>
<th>Humidity (%) Ave. ± std.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A - Spring (05/16-06/13/07)</td>
<td>19±4</td>
<td>33</td>
<td>3</td>
<td>64±11</td>
</tr>
<tr>
<td>B - Summer (08/04-08/31/07)</td>
<td>23±2</td>
<td>35</td>
<td>11</td>
<td>76±8</td>
</tr>
<tr>
<td>C - Fall (10/03-10/24/07)</td>
<td>17±5</td>
<td>32</td>
<td>3</td>
<td>72±11</td>
</tr>
<tr>
<td>D - Winter (01/04-02/05/08)</td>
<td>-3±7</td>
<td>13</td>
<td>-20</td>
<td>78±11</td>
</tr>
</tbody>
</table>

Figure 3. Schematic of the sampling system
Seasonal Variations in Ammonia Concentrations and Emission Rates

Figure 4 shows the NH$_3$ concentrations in four seasons. In the Spring, the daily average NH$_3$ concentrations varied from 111 ppm to 147 ppm with an average of $128 \pm 18$ ppm. In the Summer, the daily average NH$_3$ concentrations varied from 101 ppm to 204 ppm with an average of $167 \pm 26$ ppm. In the Fall, the daily average NH$_3$ concentrations varied from 91 ppm to 174 ppm with an average of $123 \pm 21$ ppm. In the Winter, the daily average NH$_3$ concentrations varied from 66 ppm to 278 ppm with an average of $157 \pm 70$ ppm. Statistical analysis shows the NH$_3$ concentrations in Spring and Fall are not significantly different and the concentrations in Summer and Winter were not significantly different. The high Winter NH$_3$ concentration may be caused by a few days with exceptionally high temperatures. The composting building always had high relative humidity. The air was nearly saturated, especially in Winter.

Figure 4. Seasonal variations of ammonia concentrations and indoor environment in the composting facility.

Figure 5 shows the NH$_3$ emission rates in four seasons. In the Spring, the daily average NH$_3$ emission rates varied from 202 to 267 kg/d with an average of $231 \pm 20$ kg/d. In the Summer, the daily average NH$_3$ emission rates varied from 195 to 394 kg/d with an average of $315 \pm 49$ kg/d. In the Fall, the daily average NH$_3$ emission rates varied from 187 to 352 kg/d with an average of $243 \pm 41$ kg/d. In the Winter, the daily average NH$_3$ emission rates varied from 114 to 426 kg/d with an average of $263 \pm 109$ kg/d. Statistical analysis shows the NH$_3$ emission rates in Spring, Fall, and Winter are not significantly different from each other and the emission rates in Summer were significantly different from that of the rest of seasons. The high NH$_3$ emission rates in Summer were likely due to high ambient temperatures.

Figure 5. Seasonal variation of ammonia emission rates and ambient temperature at the composting facility.
Diurnal Variation of Ammonia Emission

Figure 6 shows diurnal variations of NH₃ emission rates in three seasons. Strong diurnal variations existed in spring and summer seasons. Daytime NH₃ emission was significantly higher than that of nighttime. During daytime, NH₃ emission rates fluctuated significantly from 200 kg/d to more than 500 kg/d. The indoor air temperature did not change significantly along with the NH₃ emission. The NH₃ emission fluctuation was likely due to the composting turning operations. Since a turning machine was used to turn three rows of the compost sequentially from 8:00 a.m. to 5:00 p.m. everyday, three peaks of NH₃ emission rates were observed. The peak height may associate with the distance between the turning row and the exhaust fan, where NH₃ concentration was measured. However, in Winter, due to low ambient temperature, a relative low indoor air temperature and small diurnal variations were recorded. The NH₃ emission rate fluctuated between 150 to 200 kg/d. On January 6th, due to exceptional warm weather condition, the NH₃ emission rate was much higher and fluctuated between 350 to 470 kg/d.

Annual Ammonia Emission Rate and Emission Factors

The average NH₃ emission rates were 231±20, 315±49, 243±41, and 263±109 kg/d in Spring, Summer, Fall, and Winter, respectively. The annual emission rate of the composting facility was estimated as 96,143 kg using the seasonal average daily emission rates.

The emission factors were 10.5±1.3, 26.4±2.0, 12.3±0.9, and 12.5±1.1 kg per ton of manure per day in Spring, Summer, Fall, and Winter, respectively. The annual average emission factor was 15.4±1.3 kg/(ton d). If we use the hen number as the calculation base of the emission factors, the emission factors were 0.23, 0.53, 0.25, 0.26 g/(d hen) for the Spring, Summer, Fall, and Winter seasons, respectively. The annual average emission factor was 0.32 ± 0.14 g/(d hen). In comparison with ammonia emission rates of 0.41-0.45 g/(d hen) from the layer facilities and the composting facilities estimated by Keener et al. (2002) using a mass-balance analysis, the measurement of ammonia emission from the composting facilities is within a reasonable range.

Conclusions

The daily average NH₃ concentrations at the exhaust of the compost house varied from 123 ppm in Spring to 167 ppm in Summer. The composting building always had high relative humidity throughout the year. Statistical analysis shows the NH₃ concentrations in Spring and Fall were not significantly different and the concentrations in Summer and Winter were not significantly different.

The daily average NH₃ emission rates of the compost house varied from 231 kg/d in Spring to 315 kg/d in Summer. Statistical analysis shows the NH₃ emission rates in Spring, Fall, and Winter were not significantly different and the emission rates in Summer were significantly different from the rest of seasons.

Strong diurnal variations existed in spring and summer seasons. Daytime NH₃ emission was significantly higher that that of nighttime. During daytime, NH₃ emission rates fluctuated significantly from 200 kg/d to more than 500 kg/d. The indoor air temperature did not change significantly along with the NH₃ emission. The NH₃ emission fluctuation was likely due to the composting turning operations.

The annual emission rate of the composting facility was estimated as 96,143 kg using the seasonal average daily emission rates. The emission factors were calculated as 13±1.3 kg/(ton d) or 0.32 ±0.14 g/(d hen).

Acknowledgements. The authors would like to acknowledge that this project was supported by National Research Initiative Competitive Grant no. 2005-35112-15422 from the USDA Cooperative State Research, Education, and Extension Service Air Quality Program. Appreciation is also expressed to the participating farmer collaborators for their support to the data collection for this project. The authors would also like to thank Ms. Xinying Wang and Mr. Hui Li for their help in sample collection.
Figure 6. Diurnal variations of ammonia emission rates of the composting facility in Spring (top graph), Summer (middle graph), and Winter (bottom graph).
References


