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Abstract

Ammonia (NH3) emission from animal feeding operations (AFOs) has caused concerns on public health and environmental degradation, such as ecosystem acidification, eutrophication, and formation of PM2.5 fine particles. Current ammonia emission measurement methodologies are accurate and reliable, but time consuming, expensive, and impractical for most facilities. In the present study, an alternative and cost effective mass balance methodology was developed to predict the ammonia emission from animal facilities. The mass balance equations have been developed to eliminate needs for tracking manure flow rate to obtain accurate NH3 estimation. The methodology was applied to three manure-belt layer poultry houses with approximately 150,000 birds in each house in Ohio and validated using continuous ammonia emission measurement data. Feed, manure and egg samples were collected from the three houses in three seasons (cold, mild, and hot) to evaluate the seasonal variation of ammonia emission from the poultry facilities. Results show that this alternative mass balance method can estimate NH3 emission from manure-belt poultry layer house effectively. NH3 emission rate from manure belt poultry layer houses with manure removal every 3.5 to 5 days was 0.07-0.37 g NH3 bird-1day-1. These results agrees well with the NH3 emission values published in the previous literatures (0.027-0.616 g NH3 bird-1day-1), but were lower than the NH3 emission rate (0.1-0.86 g NH3 bird-1day-1) measured using continuous monitoring system. In the comparison analysis of NH3 measurement and estimation emissions, Normalized Mean Error (NME), Normalized Mean Square Error (NMSE) and Fractional Bias (FB) are calculated to be 52.05%, 85.32% and -70.36% respectively. This study suggests that manure removal time interval and air temperature can be important factors impacting NH3 emission. This mass balance method can only estimate total nitrogen loss in a whole production process, which is an upper bound of NH3-N loss. It is needed to quantify other nitrogen compound gas emissions, such as N2O, NOx, N2 for accurate NH3 emission estimation.

Keywords

Air quality, poultry, ammonia emission, mass balance

Disciplines

Agriculture | Bioresource and Agricultural Engineering

Comments

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Abstract. *Ammonia (NH_3) emission from animal feeding operations (AFOs) has caused concerns on public health and environmental degradation, such as ecosystem acidification, eutrophication, and formation of $PM_{2.5}$ fine particles. Current ammonia emission measurement methodologies are accurate and reliable, but time consuming, expensive, and impractical for most facilities. In the present study, an alternative and cost effective mass balance methodology was developed to predict* *the ammonia emission from animal facilities. The mass balance equations have been developed to eliminate needs for tracking manure flow rate to obtain accurate NH_3 estimation. The methodology was applied to three manure-belt layer poultry houses with approximately 150,000 birds in each house in Ohio and validated using continuous ammonia emission measurement data. Feed, manure and egg samples were collected from the three houses in three seasons (cold, mild, and hot) to evaluate the seasonal variation of ammonia emission from the poultry facilities. Results show that this alternative mass balance method can estimate NH_3 emission from manure-belt poultry layer house effectively. NH_3 emission rate from manure belt poultry layer houses with manure removal every 3.5 to 5 days was 0.07-0.37 g NH_3 bird^{-1}day^{-1}. These results agrees well with the NH_3 emission values published in the previous literatures (0.027-0.616 g NH_3 bird^{-1}day^{-1}), but were lower than the NH_3 emission rate (0.1-0.86 g NH_3 bird^{-1}day^{-1}) measured using continuous monitoring system. In the comparison analysis of NH_3 measurement and estimation emissions, Normalized Mean Error (NME), Normalized Mean Square Error (NMSE) and Fractional Bias (FB) are calculated to be 52.05%, 85.32% and -70.36% respectively. This study suggests that manure removal time interval and air temperature can be important factors impacting NH_3 emission. This mass balance method can only estimate total nitrogen loss in a whole production process, which is an upper bound of NH_3-N loss. It is needed to quantify other nitrogen compound gas emissions, such as N_2O, NO_x, N_2 for accurate NH_3 emission estimation.*

Keywords. Air quality, poultry, ammonia emission, mass balance

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1. Introduction

Ammonia emission from animal production facilities is one of the significant pollutant gases impacting public health and environmental quality. More than 80% of human-related ammonia emissions are from animal farms (Battye et al., 1994). Ammonia is regarded as the most harmful gas in poultry facilities for bird health (Carter, 1967). Its combination with particles contributes to the occurrence of ascites, gastrointestinal irritation, and respiratory disease and higher chick mortality (Leeson and Summer, 2001; Estevez, 2002). The physiological response of humans to NH_3 begins with detectable odors at 5 to 50 ppm (DeBoer and Morrison, 1988). In the environment, NH_3 causes severe acidification and eutrophication. In the Netherlands, 45% of total acid deposition was contributed by ammonia in 1989 (Groot Koerkamp et al, 1998). In addition, ammonia also contributes to the formation of secondary particulate matter dramatically (Baek and Aneja, 2004) which results in visibility degradation. The amount of ammonia emissions from poultry farms in the United States is predicted to increase from 680,000 ton yr^{-1} in 2002 to the estimated 890,000 ton yr^{-1} in 2030 (EPA, 2004). In Iowa, about 2760 to 5520 metric tons of nitrogen from laying hens was emitted into the atmosphere in 1998(Yang et al., 2000).

Current measurement of ammonia at animal facilities is mostly based on continuous monitoring of airflow and ammonia concentration level using ammonia gas analyzers (Ni and Heber, 2001). However, this method challenges farmers to evaluate the actual amount of ammonia emission because it is time consuming, costly and labor intensive. The conflicts of technologies, management of farms and urgent environment protection constrain the growth and profitability of husbandry to some extent.

An accurate, cost effective, and simple method is needed to help farmers evaluate ammonia emissions from their specific operations and the effects of their management on ammonia emission. Previous researchers have used the nitrogen balance method to estimate nitrogen loss from commercial layer facilities (Liang et al, 2004; Keener and Zhao, 2008; Yang et al, 2000; Keener et al, 2002). However, their method requires the feed, production and manure flow rate to be accurately measured. The alternative mass-balance method uses the relationship of N/Ash to avoid quantifying manure waste flow (Keener and Zhao, 2008), however, this new method needs to be further developed for practical sampling method and verified for its accuracy by the state-of-the-art measurement method.

The objectives of this study were to develop a practical sampling approach for the alternative mass-balance methodology for estimation of ammonia emission from commercial layer facilities and verification of the accuracy of the method by the continuous measurement approach.

2. Materials and methodology

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2.1 Housing and management practices

Three Ohio manure-belt poultry layer facilities on two poultry farms were selected for this study. Farm 1 is located at West Mansfield (WM), Ohio (figure 1 (a)) and farm 2 is located at Croton, Ohio (figure 1 (b)).

(a) (b)

Figure 1. Satellite image of farm layout of three layer facilities in this study.

For farm 1, two identical poultry houses were selected (figure 1 (a)). The houses were 121.9 meters long, 19.5 meters wide and 7.7 meters high at the ridge (table 1). In each house, birds were kept in eight rows and eight tiers of cages. Each row was about 100 meters long. Birds lived in the cages for about 75 weeks. Each house had 180,000 Lohmann white hens, with an initial average weight of 1.5kg at the beginning of each feeding period. Automatic feeding, watering, egg and manure collecting systems were installed in the house. Manure fell onto manure belts below the cages, and then was removed out of the building by the manure belt conveyor system twice a week. The houses had mechanical ventilation systems.

For farm 2, the selected house was 161.6 meters long, 15.85 meter wide and 7 meters high (figure 1 (b)). Birds were kept in six rows with seven tiers of cages for each row. The rows were 154 meters long. The age of bird ranged between 20 to 75 weeks during the study period. The house had about 154,500 hens with an average bird weight of 1.25kg at the time of study. Drinking nipples supplied water and chains and feed troughs provided feed to the birds. Eggs produced in the cages rolled onto the egg collection belts from bottoms of the cages. Ventilation fans were automatically controlled. Manure was removed by manure belts under the cages to the composing plant near the layer house. In this layer house, the manure belt was operated for 9 minutes each day and one fifth of total manure on the belt was removed daily. The characteristics of the layer houses and management data are summarized in Table 1.

Table 1. Characteristics and management data of three layer houses in this study

House ID	Width ×Length (meter)	Manure Removal Frequency	Vent. System	No. of Birds at start	No. of Cage Rows	No. of Cage Tiers	Measurement Period
#1	121.9×19.5	3.5 days	Cross	137575	8	7	04/12/2007-12/10/2007
#2	121.9×19.5	3.5 days	Cross	164285	8	7	04/12/2007-12/10/2007
#3	161.6×15.9	5 days	Cross	154692	6	7	04/21/2008-03/05/2009

2.2 Mass balance using N/Ash theory

The nutrient mass balance in animal production facility denotes that the input nutrient mass flow of an animal production system is equal to the output nutrient flow. A nitrogen balance approach, accounting for inputs and outputs of nitrogen, has been used to analyze nitrogen loss from animal production facility (Liang et al, 2004; Keener and Zhao, 2008; Yang et al, 2000; Keener et al, 2002).

In a poultry egg production system (figure 2), the inputs include air, water, feed, and laying hens entering the production system and the outputs include air, eggs, manure, mortality, and gas emission leaving the facility. Nitrogen in the air entering and leaving the system does not participate in the nitrogen conversion process and nitrogen in drinking water is negligible. Laying hen Body weight change of laying hen can be negligible over the production period. Mortality is very low in one day (20 mortality in 0.15 million chicken). Nitrogen gas loss from a poultry house is mainly in the form of ammonia (NH_3) gas emission. Therefore, estimation of nitrogen gas emission determines the upper limit of NH_3 emission from a poultry production system. According to the above assumptions, figure 2 can be simplified into figure 3.

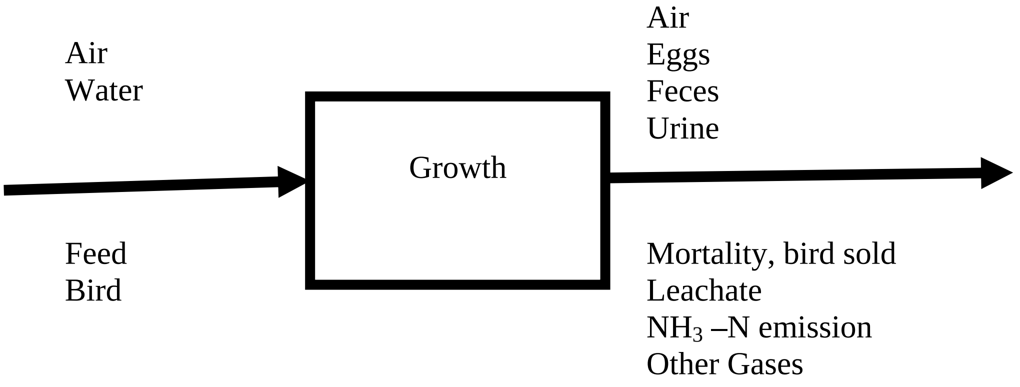

Figure 2. Schematic of a poultry eggs production system with input, storage and output variables (Keener and Zhao, 2008).

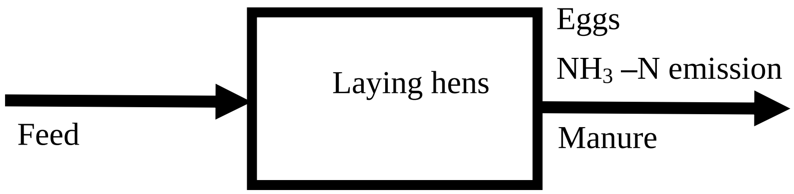

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Figure 3. Simplified schematic of an eggs production system with input, storage and output variables.

The nitrogen balance for the system is demonstrated by equation 1

$$x_{N1}m'_1 \cong x_{N3}\frac{dm_i}{dt} + x_{N2}m'_2 + N_4 \tag{1}$$

The ash balance for the system is described by equation 2

$$x_{A1}m'_1 \cong x_{A3}\frac{dm_i}{dt} + x_{A2}m'_2 \quad \longrightarrow \quad \frac{dm_i}{dt} \cong (x_{A1}m'_1 - x_{A2}m'_2)/x_{A3} \tag{2}$$

So the ammonia emission (NH_3-N) can be calculated in equation 3

$$\begin{aligned} N_4 &\le x_{N1}m'_1 - x_{N2}m'_2 - x_{N3}\frac{dm_i}{dt} = x_{N1}m'_1 - x_{N2}m'_2 - x_{N3} * (x_{A1}m'_1 - x_{A2}m'_2)/x_{A3} \\ N_4 &\le x_{N1}m'_1 - x_{N2}m'_2 - R_3(x_{A1}m'_1 - x_{A2}m'_2) \end{aligned} \tag{3}$$

Table 2. Variables used in mass balance equation for poultry house

Variables	Subscript
t= time, day m_i= mass of i, kg m'_i =mass flow rate of i, kg/day, dry base dm_i/dt= rate of mass change, kg/day x_{Ni}=nitrogen content, dec x_{Ai}=ash content, dec N_4=NH_3-N emission R_3=N to Ash in manure= x_{N3}/x_{A3}	i=1, feed in 2, eggs out 3, manure

In the traditional nitrogen mass balance method (Liang, 2004; Yang, 2000), manure flow quantification was necessary to estimate accurately NH_3 emission. However, it is a challenge to acquire accurate manure flow rates in an animal production system. The alternative nitrogen and ash balance method presented here avoids direct monitoring of manure flow rates and can lead to accurate estimation of NH_3 emission using parameters which are easier to measure or obtain accurately.

The error in estimation of NH_3 emission may be caused by five factors including errors in nitrogen and ash content of feed (x_{N1} and x_{A1}), errors in nitrogen and ash content of eggs

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(x_{N2} and x_{A2}), and errors in N/Ash content ratio of manure (R_3) (equation 3). The total estimated error is given in equation 4 (Taylor, 1997).

$$\Delta N_4 = \sqrt{(\Delta x_{N1} * \frac{\partial N_4}{\partial x_{N1}})^2 + (\Delta x_{N2} * \frac{\partial N_4}{\partial x_{N2}})^2 + (\Delta R_3 * \frac{\partial N_4}{\partial R_3})^2 + (\Delta x_{A1} * \frac{\partial N_4}{\partial x_{A1}})^2 + (\Delta x_{A2} * \frac{\partial N_4}{\partial x_{A2}})^2}$$

$$= \sqrt{(\Delta x_{N1} * m'_1)^2 + (\Delta x_{N2} * m'_2)^2 + (\Delta R_3 * (x_{A1} * m'_1 - x_{A2} * m'_2))^2 + (\Delta x_{A1} * R_3 * m'_1)^2 + (\Delta x_{A2} * R_3 * m'_2)^2} \tag{4}$$

The relative standard error is calculated as standard deviation divided by mean value for results, which can indicate the error variance in the estimated ammonia emission results.

2.3 Sampling methods and procedures

The objective of the sampling plan is to obtain representative samples at each poultry house to estimate the NH_3-N emission in different seasons. The first two houses were sampled from April to December 2007 and the third house from April 2008 to March 2009.

At farm 1, samples of feed, eggs and manure were collected in April, June, July, September, and December of 2007. The total number of sampling days was seven at house 1 and six at house 2. In each day, three 500g feed samples were collected from the feed bin and three eggs samples were collected from the egg belt randomly. One spoon of manure was collected at the end of manure belt every 5 to 6 minutes using a 250mL polyethylene sampler when the manure fell down from the manure belt to the transporter. Five 250ml manure subsamples were collected and mixed for each belt to form one sample. The manure belt conveyors under the cages moved simultaneously with constant speed. A total of five manure samples were obtained respectively from the terminal end of five manure belt conveyors under the cages at each sampling event.

At farm 2, there were three sampling days in spring (April, 2008), three in summer (August, 2008), one in September, one in October, one in December 2008 and one in March 2009. One fifth of the manure on the conveyor belt under cages was removed daily. Collective samples were obtained from each belt as the manure fell onto the main conveyor belt leading out of the house. There were six cage rows and the conveyors belt ran in sequence for 9 minutes each day. For each row, 6 subsamples were collected with a 250 ml polyethylene sampler. Subsamples of each row were mixed to form one sample. Finally, manures from six rows were collected to form respectively six samples on each sampling day. Three eggs samples were picked randomly in the house on each sampling day. Three feed samples were taken from the feed bin supplying this house directly on each sampling day.

Weekly bird production, daily feed consumption and eggs production, bird age and body weight for the three poultry houses were recorded by the producers. The data was collected from the producers.

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2.4 Lab analysis of feed, eggs, and manure samples for ash, total nitrogen and dry matter contents

According to the N/A mass balance equations, ash, total nitrogen and total solid values of the samples are needed for the calculations. Ash in all samples was tested using TMECC 03.02-A. Unmilled material was ignited at 550°C without inerts removal (The U.S. Composting Council). Total nitrogen in feed, eggs and manure was tested using Combustion Method in AOAC Official Method 990.03 (Sweeney, 1989). Total solid was tested using TMECC 03.09 total solid by weighing (The U.S. Composting Council). All samples were analyzed in the Service Testing and Research (STAR) lab at OARDC, Wooster, Ohio.

2.5 Ammonia emission rate measurement

The ammonia emission rate was also monitored using the state-of-the-art continuous emission monitoring method (Wang, 2007; Heber et al, 2006) from April 2007 to February 2008 at farm 1. The ammonia emission rate from the poultry building was calculated by multiplying ammonia concentration difference between building exhausts and inlets by the house ventilation rate (equation 5). The equation used for the calculation is:

$$E = \sum_{k=1}^{n} \left[Q_{o,k} \left(C_{o,k} - C_i \right) \right] \tag{5}$$

Where

E is Gas emission rate from the house (mg/s);

$C_{o,k}$ is Mass concentration at ventilation exhaust location k (mg/m^3 or µg/m^3);

C_i is Mass concentration in incoming ventilation air (mg/m^3 or µg/m^3); and

$Q_{o,k}$ is Ventilation rate at ventilation exhaust location k (m^3/s)

Continuous emission monitoring equipment housed in a mobile air emission lab (Zhao et al, 2008) were used to measure the inlet and outlet ammonia concentrations and ventilation rate of the first and second houses at the same time when the alternative mass balance sampling and analysis was also conducted.

2.6 Temperature measurement in poultry houses

Indoor temperature was monitored during each sampling event in three poultry houses. For house 1 and house 2, temperature was measured using thermocouple sensors (Wang, 2007). For house 3, a Vaisala portable sensor was employed to monitor temperature according to the sampling layout shown in figure 4. The ambient temperature and relative humidity were obtained from the local weather station record (wunderground.com).

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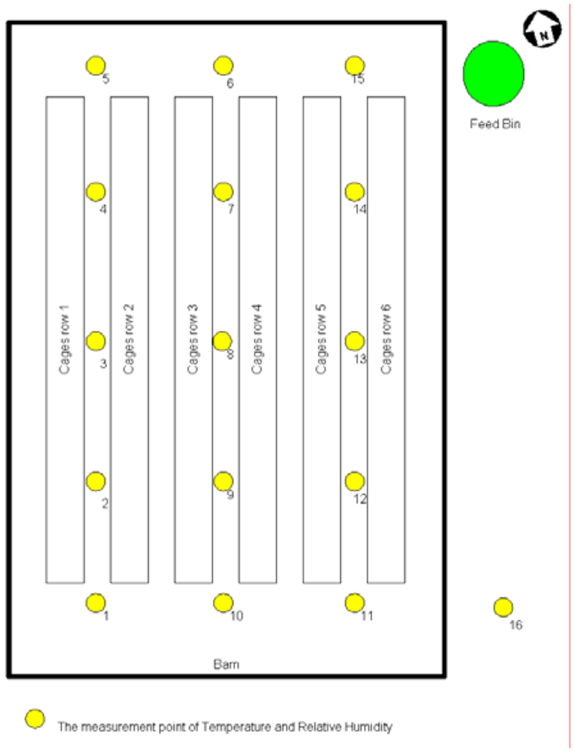

Figure 4. Measurement points of indoor temperature and relative humidity in house 3

2.7 Statistical comparison of measured and estimated ammonia emissions

The Normalized Mean Error (NME), Normalized Mean Square Error (NMSE) and Fractional Bias (FB) were computed to compare the ammonia emission rates estimated by the alternative mass balance method and measured by the mobile lab measurement method.

$$NME = \sum \left| C_{Pi} - C_{Oi} \right| / \sum C_{Oi} \qquad (6)$$

$$NMSE = \sum \left| C_{Pi} - C_{Oi} \right|^2 / (nC_P C_O) \qquad (7)$$

$$FB = 2(C_P - C_O)/(C_P + C_O) \qquad (8)$$

Where,

C_{Pi}: Ammonia estimation value, g bird^{-1}day^{-1}
C_{Oi}: Ammonia measurement value, g bird^{-1}day^{-1}
n: Number of corresponding estimation and measurement values
C_P: Mean estimation value, g bird^{-1}day^{-1}
C_o: Mean measurement value, g bird^{-1}day^{-1}

3 Results and discussions

3.1 Weather conditions

The variation of annual ambient temperature ranged from -7.78°C to 21.67°C with a mean of 9.62°C at farm 1 and -17.2°C to 32.8°C with a mean of 13.5°C at farm 2.

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Relative humidity (RH) ranged from 30% to 85% with a mean of 54% at farm1, and from 17% to 100% with a mean of 76% at farm 2. The temperature inside the first and second layer house ranged from 19 to 29^{o}C. The temperature in the third house ranged from 18 to 31^{o}C during monitoring period.

3.2 Ash, nitrogen contents in feed, eggs and manure samples

The ash content of poultry feed varied from 13.16% to 14.98% and total nitrogen ranged from 2.57% to 3.31% (table 3).

Ash values of the manure ranged from 30.8% to 33.91% and had a small variance in all samples (coefficient of variation<2.7%). Total nitrogen varied from 4.18% to 5.97%. Chicken manure was alkaline in nature with a pH value range of 7.23-8.20. N/A value was almost constant, from 0.15-0.18 (table 3).

Ash and total nitrogen in eggs were almost constant. Ash value ranged from 33.29% to 33.55% and total nitrogen from 5.78% to 5.79 % on a dry weight base (table 3).

Table 3. Nutrient contents and pH value of chemical analysis of feed, eggs and manure samples

Description	House #	pH (mean±std)	Ash (%) (mean±std)	Total nitrogen (%) (mean±std)	C/N (mean±std)
Feed	1	N/A	13.67±0.21	3.07±0.48	N/A
	2	N/A	13.16±0.67	2.57±0.21	N/A
	3	N/A	14.98±2.01	3.31±0.29	N/A
Eggs	1	N/A	33.55	5.79	N/A
	2	N/A	33.55	5.79	N/A
	3	N/A	33.29±0.46	5.78±0.15	N/A
Manure	1	7.23±0.54	33.08±2.07	4.85±0.72	0.17±0.03
	2	7.53±0.60	33.91±1.71	4.18±0.57	0.15±0.02
	3	8.20±0.64	33.17±2.29	5.97±0.79	0.18±0.01

3.3 Feed consumption and eggs production

Data on feed consumption and eggs production varied seasonally because of the bird age and indoor environmental conditions of the poultry houses (table 4). Fresh layers (20 weeks age) accommodated in house 3 consumed less feed and produced lower weight of eggs each day in comparison with the elder birds (30-40 weeks age) of house 1 and house 2.

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Table 4. Feed Consumption and eggs production

Houses	Birds Number	Feed Consumption ($g.bird^{-1}.day^{-1}$) dry base	Eggs production ($g.bird^{-1}.day^{-1}$) dry base
#1	162928(June, 2007)- 162153 (July, 2007)	81.1-103.0	16.3-19.6
#2	164285(April, 2007)- 157195(December, 2007)	93.91-104.6	16.8-18.8
#3	154692(April, 2008)- 146598(March, 2009)	77.7-91.2	7.5-13.9

3.4 Ammonia emission from poultry houses

Table 5 summarizes the ash, nitrogen contents, and materials flow and ammonia emission estimation using the alternative mass balance method for three layer houses. The corresponding figure 5, 6 and 7 depict the trend of estimated and measured ammonia emissions from the three layer houses.

There were not obvious seasonal differences in the ammonia (NH_3-N) emission results from three poultry houses. For house 1, the estimated NH_3-N emission rate using the mass balance method ranged from 0.057±0.052 to 0.308±0.109 g $bird^{-1}day^{-1}$, which is less than the continuously monitoring values of 0.10-0.61 g $bird^{-1}day^{-1}$. However, the variation trends of two methods are similar in this house (figure 5). For house 2, the estimated NH_3-N emission rate using this mass balance method ranged from 0.045±0.116 to 0.239±0.113g $bird^{-1}day^{-1}$, which is less than the continuously monitored value of 0.15-0.41 g $bird^{-1}day^{-1}$. However, the variation trend of two methods is similar before July (figure 6). For house 3, the estimated NH_3-N emission rate using this mass balance method ranged from 0.045±0.116 to 0.239±0.113g $bird^{-1}day^{-1}$.

Manure management in a poultry house impacts the NH_3-N emissions significantly (Kroodsma et al, 1988; Buijsman and Erisman, 1988; Groot Koerkamp, 1994; Keener et al, 2002; Liang et al, 2004). Manure in the first and second houses was removed twice weekly. Manure from the third house was removed one fifth of total manure by the conveyor belt each day. Manure in house 3 was moved once every 5 days, compared to 3.5 days for houses 1 and 2. In previous studies, the higher frequency of manure removal resulted in less NH_3-N emission due to a shorter retention time of manure in the house (Groot Koerkamp, 1994; Liang et al, 2004). The emission rate in house 3 ranges from 0.03±0.11 to 0.19±0.06 g $bird^{-1}day^{-1}$, less than that from house 1 and 2, from 0.06±0.05 to 0.31±0.11 g $bird^{-1}day^{-1}$. The large ranges in values are possibly caused by non-uniform sampling of manure.

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Table 5. Nitrogen and ash balance (g bird^{-1} day^{-1}) for three layer houses for one year

		Feed		Eggs		N/A in manure	Mass flow (gbird^{-1} day^{-1}) Dry base		NH$_3$-N emission (gbird^{-1} day^{-1})
	House	N (%)	Ash (%)	N (%)	Ash (%)		Feed	Eggs	
March	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	3	3.42	12.72	5.54	33.44	0.19	89.59	11.47	0.196
April	1	2.33	13.54	5.81	33.62	0.14	102.97	18.83	0.057
	2	2.41	13.52	5.81	33.63	0.15	102.97	18.83	0.065
	3	3.53	14.04	6.02	34.24	0.19	78.58	7.95	0.142
June	1	2.94	13.52	5.84	33.62	0.13	85.43	16.26	0.212
	2	2.61	13.52	5.83	33.61	0.19	99.38	18.38	0.045
	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
July	1	3.37	13.81	5.79	33.55	0.19	86.39	18.43	0.209
	2	2.55	13.14	5.79	33.55	0.13	94.61	17.74	0.153
	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
August	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	3	3.25	15.77	5.70	33.07	0.18	90.79	13.82	0.082
Septem	1	3.45	13.38	5.79	33.55	0.17	95.11	19.63	0.308
	2	2.60	11.78	5.79	33.55	0.14	104.62	16.84	0.228
	3	3.30	16.30	5.60	33.60	0.17	90.71	12.29	0.096
October	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	3	3.00	15.90	5.90	33.3	0.18	90.97	13.79	0.032
December	1	2.90	13.90	5.79	33.55	0.18	101.96	18.98	0.125
	2	2.90	13.90	5.79	33.55	0.15	98.09	18.57	0.193
	3	3.20	15.60	5.50	33.40	0.16	91.17	13.79	0.112

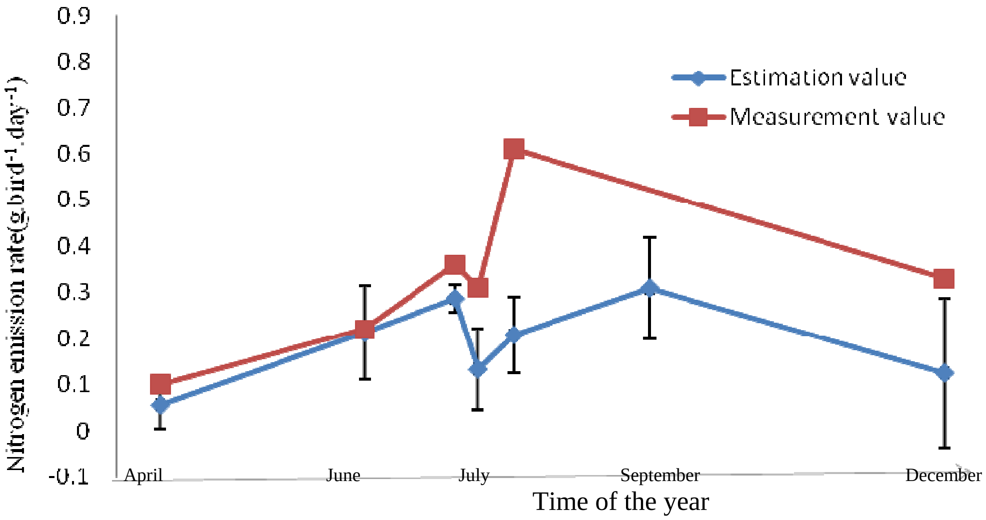

Figure 5. Estimation and measurement value of ammonia emission in house 1

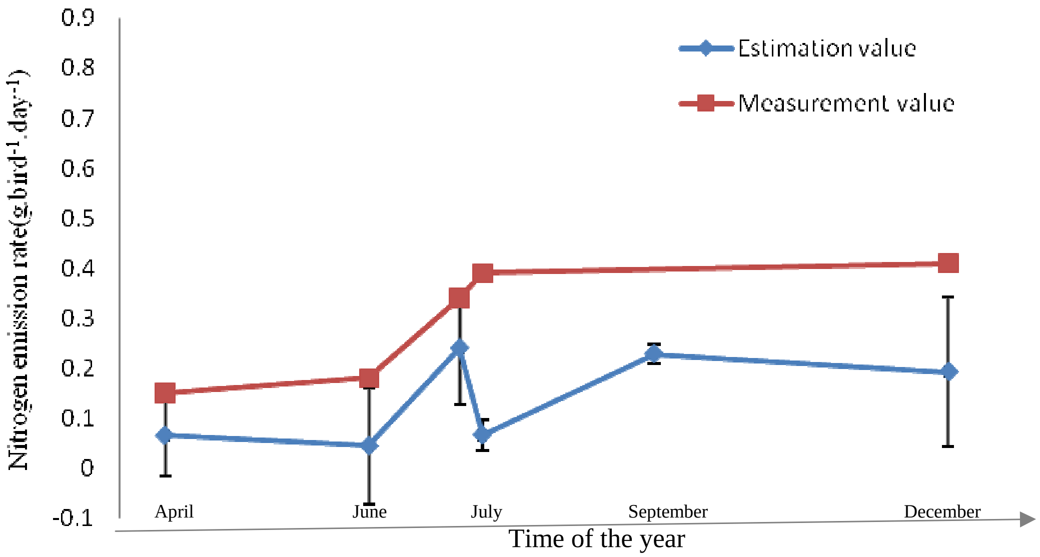

Figure 6. Estimation and measurement value of ammonia emission in house 2

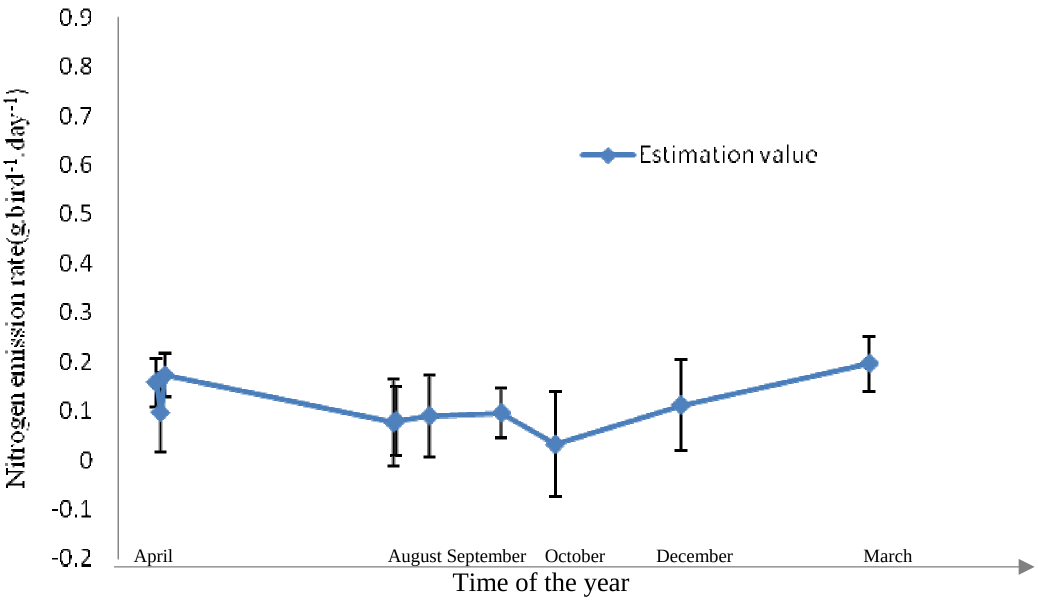

Figure 7. Estimation and measurement value of ammonia emission in house 3

Although obviously higher emission rate were found in the warmer seasons in measurement results, there was not significantly seasonable variance observed in the estimation results using this alternative mass balance method in three poultry barns (P> 10%). The estimation standard error of the estimation results shown in figure 5, 6 and 7, are caused by the accumulation error of factors (equation 4).

3.5 Error analysis

The relative standard error is used to analyze error of the estimation results in three poultry layer houses using N/A mass balance method. Relative standard error equals the results of total error divided by mean value of estimation results. Table 6 shows the range of relative standard error of estimation results in three houses. For results from N/A mass balance method, the error ranged from 8.50% to 332.23% in three houses.

The larger errors of estimation results in three poultry layer houses were caused by the accumulation of each factor error. Five factors on production data and sample components were used to calculate the estimation value in three poultry houses. The non-uniform collection of samples resulted in the minor error, accumulating into the larger error of estimation emission, observed in the error analysis.

Table 6. Relative standard error in the estimation results in three poultry layer houses

N/A Mass balance method	House 1	House 2	House 3
Relative standard error (%)	10.41-92.30	8.50-260.96	25.63-332.23

3.6 Statistical comparison of measured and estimated ammonia emissions

In the comparison of measurement and estimation of ammonia emissions at 11 pair of values of house 1 and house 2, NME, NMSE and FB are calculated to be 52.05%, 85.32% and -70.36% respectively. Three higher statistical values for measurement and estimation ammonia emission results are caused possibly by the instrument measurement error and sampling error of feed, eggs and manures.

3.7 Relationship of indoor temperature and manure pH with ammonia emission rate

Temperature is a significant factor affecting ammonia emission in AFOs (Keener and Zhao, 2008; Arogo et al, 2002). High temperature in a house can facilitate the growth of microorganism decomposing the organic nitrogen in manure and increase the ammonia concentration in animal house (Arogo et al, 2002). In the three houses, there is no strong linear relationship between indoor temperature and ammonia estimation, indoor temperature and ammonia measurement (table 7; figure 8). For the individual house, the estimation and measurement results at the first house have stronger passive linear relationship with indoor temperature (r=0.73 and 0.67 respectively) (table 7).

The chemical equilibrium equations for ammonia and ammonium ion are given in equations 9, 10 and 11.

$$NH_4^+\text{(liquid)} \Leftrightarrow NH_3\text{ (liquid)} + H^+ \quad (9)$$

$$NH_3\text{ (liquid)} \Leftrightarrow NH_3\text{ (gas)} \quad (10)$$

$$NH_3\text{ (gas in manure)} \Leftrightarrow NH_3\text{ (gas in ambient air)} \quad (11)$$

At a high pH value in manure, $[H]^+$ is reduced and liquid ammonium is converted to liquid ammonia, and then gaseous ammonia (Yang et al, 2000). In three houses, manure pH results does not show the stronger linear relationship with estimation and measurement results based on the correlation coefficient (table 7; figure 9). For the individual house, the estimation results at the third house and measurement results at the second house have stronger passive linear relationship with manure pH value (r=0.67and 0.69 respectively) (table 7).

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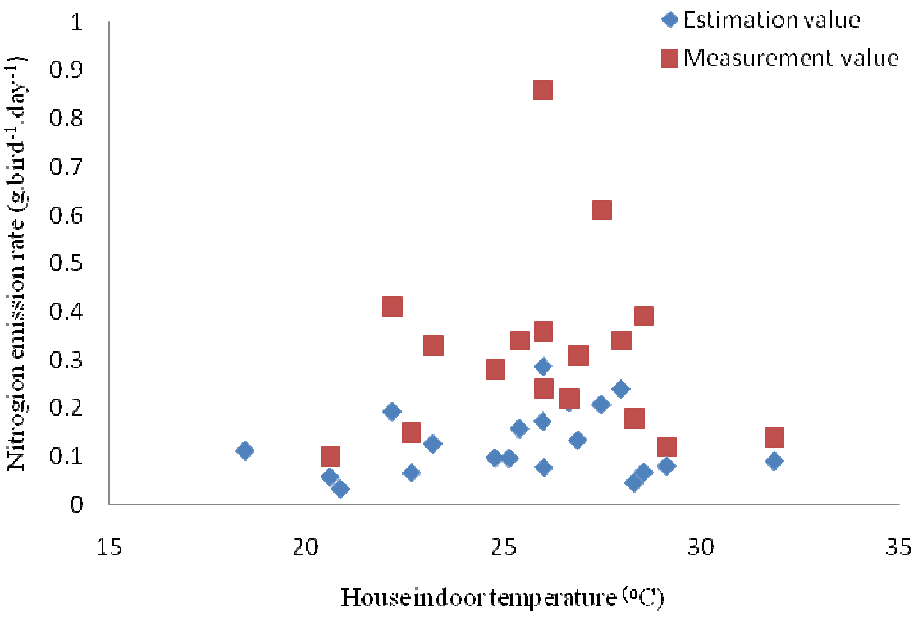

Figure 8. Relationship of estimated ammonia emission and indoor temperature in three houses

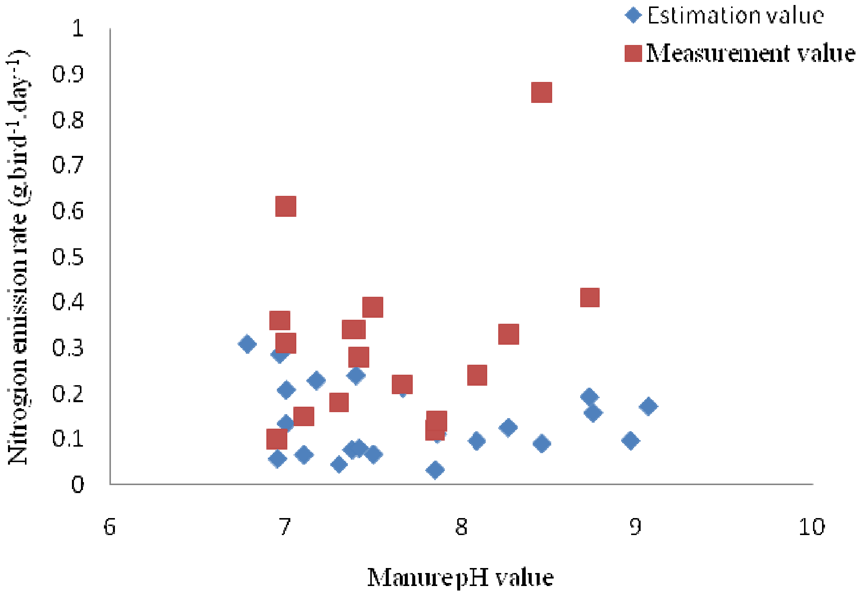

Figure 9. Relationship of estimated ammonia emission and manure pH value in three houses

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Table 7. The correlation coefficient for ammonia emission, indoor temperature and manure pH value

	r (correlation coefficient)	Indoor Temperature (^{o}C)		Manure pH	
		E*	M*	E*	M*
Ammonia	First house	0.73	0.67	-0.31	-0.10
	Second house	-0.15	0.07	0.27	0.69
	Third house	0.09	N/A	0.67	N/A
	Total	0.15	0.39	-0.17	0.18

*E: Estimation value; M: Measurement value

3.8 Comparison of published ammonia emission values with that of this study

The upper limit of ammonia emissions ranged from 0.03±0.11 to 0.31±0.11g NH_3-N bird^{-1}day^{-1} in manure belt system using alternative mass balance method. These values are comparable to ammonia emission rates reported in published literatures under the similar manure management system (table 8).

Table 8. Comparison of ammonia emission values from published literatures and current study

Studies	Emission Rate g NH_3.day^{-1}. Bird^{-1}	Housing & manure systems	Manure Removal Interval
Kroodsma et al. (1988)	0.093	Manure belt	Twice a week with no manure drying
Kroodsma et al. (1988)	0.084	Manure belt	Once a week with manure drying
Buijsman (1988)	0.575	Belt battery cage system	N/A
Groot Koerkamp (1994)	0.027	Belt battery cage system	Daily
	0.093		Weekly
Keener et al. (2002)	0.616	Belt composting system	Twice weekly
	0.107	Belt battery caged system	Twice weekly
Müller et al. (2003)	0.046-0.173	Belt battery cage system	N/A
Liang et al. (2004)	0.054±0.0048	Manure belt	Daily with no manure drying
	0.094±0.019	Manure belt	Twice a week
This study	0.10-0.86	Manure belt system (monitoring equipment)	
	0.06±0.05-0.31±0.11	Manure belt system (alternative mass balance)	Twice a week
	0.03±0.11-0.19 ±0.06	Manure belt system (alternative mass balance)	20% of total manure each day

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4 Conclusions

The alternative mass balance method can be used to estimate ammonia emission from manure-belt poultry layer house effectively. The feed, eggs and manure sampling schedules and procedures have been developed to obtain the representative samples to estimate ammonia emission more accurately.

The annual average NH_3-N emission based on this alternative methodology, for the manure-belt poultry layer houses with manure removal every 5 and 3.5 days was 0.03±0.11-0.31±0.11 g NH_3-N $bird^{-1}day^{-1}$.Significant seasonal variation of estimation results was not observed in three houses (P>10%).

These results agree well with the emission values available in other published literatures (0.027-0.575 g NH_3 $bird^{-1}day^{-1}$), but were lower than the measured ammonia emission by continuous monitoring systems (0.1-0.86 g NH_3 $bird^{-1}day^{-1}$). In the comparison analysis of measurement and estimation ammonia emissions from house 1 and house 2, NME, NMSE and FB are calculated to be 52.05%, 85.32% and -70.36% respectively. These higher statistical values from measurement and estimation ammonia emission results are caused possibly by both the instrument measurement error and the sampling error of feed, eggs and manure.

For house 1, indoor temperature has stronger linear relationship with estimation and measurement emission results. For house 2, this relationship is also found between manure pH value and measurement emission results. For house 3, estimation results show stronger linear relationship with manure pH value.

It is to be noted this mass balance method can only elicit the total nitrogen loss in the whole production process and estimate an upper bound on NH_3 loss. Because at the poultry facility, other nitrogen compounds in gaseous forms such as N_2O, N_xO, N_2 co-exit with ammonia, thus additional monitoring requirements and tools are needed to quantify these gases and predict ammonia emission more accurately.

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References

Arogo, J., P.W.Westerman, A.J. Heber, W. P. Robarge, and J.J. Classen. 2002. Ammonia emissions from animal feeding operations. White paper for National Center for Manure and Animal Waste Management, North Carolina State University.

Baek, B.H., and V. P. Aneja. 2004. Measurement and analysis of the relationship between ammonia, acid gases, and fine particles in the eastern North Carolina. J. Air and Waste Manage. Assoc. 54(5): 623-633.

Battye, R., W. Battye, C. Overcash, and S. Fudge. 1994. Development and selection of ammonia emission factors. EPA/600/R-94/190. Final report prepared for U.S.Environmental Protection Agency, Office of Research and Development. USEPA. Contract No. 68-D3-0034, Work Assignment 0-3.

Buijsman, E., J.W.Erisman. 1988. Wet deposition of ammonium in Europe. Journal of Atmospheric Chemistry 6: 265-280.

Carter. 1967. Environmental Control in Poultry Production. Oliver and Boyd Ltd. London.

DeBoer, S. and W. D. Morrison. 1988. The Effects of the Quality of the Environment in Livestock Buildings on the Productivity of Swine and Safety of Humans, a Literature Review. University of Guelph, Guelph, Ontario, Canada, N1G 2W1.

Environmental Protection Agency (EPA). 2004. National emission inventory-ammonia emissions from animal husbandry: www.epa.gov/ttn/chief/net/2002inventory.html.

Estevez I.2002. Ammonia and poultry welfare. Poultry Perspectives Newsletter 4(1), spring 2002.

Groot Koerkamp, P.W.G. 1994. Review on emissions of ammonia from housing systems for laying hens in relation to sources, processes, building design and manure handling. Journal of Agricultural Engineering Research 59(2): 73-87.

Groot Koerkamp, P.W.G., J.H.M. Metz, G.H. Uenk, et al. 1998. Concentrations and emissions of ammonia in livestock buildings in north Europe. J. agric. Engng Res. (1998) 70, 79-95.

Heber, A.J., J.Ni, T.T.Lim, P. Tao, A.M. Schmidt, J.A.Koziel, D.B.Beasley, S.J.Hoff, R.E. Nicolai, L.D. Jacobson and Y.Zhang. 2006. Quality assured measurements of animal building emissions: gas concentrations. J Air Waste Manag Assoc. 2006 Oct; 56 (10):1472-83.

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Keener, H.M., D.L. Elwell and D. Grande. 2002. NH_3 emissions and N-balances for a 1.6 million caged layer facility: manure belt/ composting Vs. deep pit operation. Transactions of ASAE. Vol. 45(6): 1977-1984.

Keener, H.M. and L. Zhao. 2008. A modified mass balance method for predicting NH_3 emission s from manure N for livestock and storage facilities. Biosystem Engineering 99(2008): 81-87.

Kroodsma, W. R. Scholtens, J.Huis. 1988. Ammonia emission from poultry housing systems. New York, N.Y.: Elsevier Applied Science.

Leeson S. and J. D. Summers. 2001. Nutrition of the Chicken. 4th edition. University Books. Ghelph, Ca.

Liang, Y., H. Xin, and E.F. Wheeler. 2004. Ammonia emission from U.S. laying hen houses in Iowa and Pennsylvania. Transactions of the ASAE 48(5): 1927-1941.

Muller H. J., R. Brunsch, G. Hornig, A. Jelinek. 2003. Odour and ammonia emissions from poultry houses with different keeping and ventilation systems. In International Symposium on Gaseous and Odour Emissions from Animal Production Facilities. 1-4 June 2003: 172-179. CIGR. EurAgEng, NJF.

Ni, J. and A. J. Heber. 2001. Sampling and measurement of ammonia concentration at animal facilities- a review. ASABE meeting paper No. 014090. St. Joseph, Mich.: ASABE.

Ohio Livestock Coalition. 2009. http://www.ohiolivestock.org/About/Partners.html.
Sweeney, R., JAOAC 72:770 (1989).

Taylor, J.R. An introduction to error analysis. CA: University Science Books, 1997.
The U.S. composting council. Test Methods for the Examination of Composting and Compost (TMECC).

Wang, X. 2007. Modeling of ammonia emission from poultry layer facilities. MS Thesis , Columbus, Ohio: The Ohio State University, Department of Food, Agricultural and Biological Engineering.

Yang, P., J. C. Lorimor and H. Xin. 2000. Nitrogen losses from laying hen manure in commercial high-rise layer facilities. Transaction of the ASABE 43(6): 1771-1780.

Zhao, L., R.Manuzon, M.Darr, H. Keener, A.J.Heber, and J. Ni. 2008. Ammonia emissions from a commercial poultry manure composting facility. ASABE meeting paper No. 701P0408. St. Joseph, Mich.: ASABE.