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The Uncertainty of Nitrogen Mass Balance for Turkey Housing

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Summary and Implications

Quantification of ammonia (NH_3) loss from animal feeding operations by measuring gaseous concentration and air exchange through the emitting source is not always practical, e.g., under natural ventilation conditions. Mass balance over an extended period of time may offer a possible remedy. This study compares two NH_3-N emission estimate approaches for a commercial turkey grow-out house over one year period: a) a concentration-flow-integration (CFI) method (considered as the reference method), and b) a nitrogen (N) mass-balance (NMB) method. The CFI NH_3-N emission was determined by continuously measuring the NH_3 concentration and exhaust air flow rate through the turkey house with a state-of-the-art mobile air emission unit. The mass-balance N emission was calculated by balancing the total N inputs (new bedding, young birds, feed) and N output (litter cake removed between flocks, litter removed at cleanout, amount of marketed birds, mortality, and bird body N content), as per records kept by or presented to the cooperative producer. The results revealed a large discrepancy (6273 vs. 2010 kg) in NH_3-N loss between the NMB and CFI methods. The outcome of this study cast serious doubt about the adequacy of using mass balance for estimating NH_3 emissions from a dynamic production system such as turkey houses.

Introduction

The standard method used for measuring ammonia (NH_3) emission from an animal building is to monitor NH_3 concentrations of incoming and outgoing air streams and air flow rates through the building. This method may be referred to as concentration-flow-integration (FCI) method. The FCI method requires continuous measurements of NH_3 concentrations, fan operation, building static pressure, calibrated fan curves (periodic), interior temperature and relative humidity, and atmosphere pressure. Alternatively, nitrogen mass balance (NMB) method could be used to determine the NH_3 loss by balancing the total N inputs and N output. Compared to the CFI method, the NMB method would incur lower capital and operating costs. However, there are more components where human errors could be introduced into the process, particularly in keeping track of the feed delivery tickets, weight/record of the new bedding or removed litter, head count on the placement and/or marketed animals, representativeness of the litter sampling, animal sampling, and analyses of samples. To apply NMB reliably and effectively, the method must be tested for its adequacy by quantifying its uncertainty. The uncertainty analysis involves a) identifying major uncertainty sources; b) quantifying their relative importance to the overall uncertainty; c) determining their effects on the final results. Such a uncertainty analysis could provide a better understanding on the potential limitations of the NMB approach and strategies to reduce NMB uncertainty.
The paper assesses NMB vs. CFI (reference) methods for estimating NH_3 emission from a tom turkey grow-out barn, to determine the relative contributions of individual factors to total uncertainty of NMB, and to suggest ways to reduce NMB uncertainty.

Materials and Methods

A commercial turkey grow-out house was monitored for NH_3, PM_{10}, and $PM_{2.5}$ emissions over one-year period (2007-2008). At five weeks of age, the Hybrid tom turkeys (4000-6000) were moved from a brooder barn to the grow-out barn where they were raised till market age of 20-21 weeks. Standard commercial diets were fed *ad lib* to the birds during the study. An automatic bird scale was placed in the barn to continuously monitor bird weight. Daily bird mortality was also recorded. During the one-year period, three flocks of tom turkeys were monitored and samples were collected and analyzed. A state-of-the-art mobile air emissions monitoring unit (MAEMU) was used to continually monitor the NH_3 emission.

The difference between nitrogen (N) inputs and outputs were assumed to reflect the N losses mainly due to gaseous NH_3 emission. The N losses from nitrate leaching and denitrification as other forms of nitrogen ─ NO (nitric oxide), N_2O (nitrous oxide), and N_2 were considered negligible. The N content of each mass balance component was obtained by analyzing representative samples.

$$N_{input} = N_{output}$$

where N_{input} = N input from feed, young birds, bedding;
N_{output}= N output in marketed birds, mortalities, litter, and as NH_3

Therefore, N loss as NH_3 could be derived from following:

$$N_{NH_3} = N_{feed} + N_{youngbird} + N_{bedding} - N_{marketebird} - N_{mortality} - N_{litter}$$

$$N_i = R_i \times W_i$$

where R_i = ratio of N content to total weight for a given N component
W_i = weight of the given N component, kg

$$N_{NH_3} = R_{feed} \times W_{feed} + R_{youngbird} \times W_{youngbird} + R_{bedding} \times W_{bedding} - R_{marketedbird} \times W_{marketedbird} - R_{mortality} \times W_{mortality} - R_{litter} \times W_{litter}$$

The amount of feed used by the flock was tracked with the feed delivery tickets provided by the producer. Feed samples were taken weekly from the feed hoppers and were analyzed in duplicates for TKN content in a Nutritional Analytical Lab at Iowa State University. The N content of individual feed formulation with the corresponding feed weight was used to calculate the total feed N input. The N output of caked litter or litter from each cleanout was calculated based on the N content and weight of the litter. The numbers of birds marketed were obtained from the producer and initial young bird numbers were derived by adding the daily mortality from the farm records to the final number of marketed birds. Eight birds were sampled upon transfer of the birds from the brooder barn to the grow-out barn for each flock. At the end of each flock, seven birds were sampled on the day of flock harvest. The bird samples were analyzed for TKN content. The mortalities were not sampled for body N content. Instead, it was predicted by a linear interpolation of N contents at the start and end of the flock. Then, the cumulative N output in mortality was determined from daily mortality and body weight record. The amount of new bedding added to the house and the amount of litter removed from the house were each weighed and provided to the research team by the cooperative producer. Fresh bedding and used litter were sampled and analyzed as-is for TKN without drying process.

Uncertainty is a measure of the reliability associated with a particular set of measurements and can be expressed in statistical terms. The general form of the expression for determining the uncertainty of a measurement is the root sum-square of the systematic and random standard uncertainties of the measurement, namely,

$$\delta = \sqrt{\beta^2 + s^2}$$

where β = systematic standard error or bias
s = random standard error of the mean or precision

The expanded uncertainty of the measurement mean is the total uncertainty at a defined level of confidence. For applications in which a 95% confidence interval (CI) is appropriate, the expanded uncertainty is calculated as follows:

$$\Delta = 2\delta$$

Expanded uncertainty is used to establish a confidence interval about the measurement mean which is expected to contain the true value. Thus, the interval MEAN ± Δ is expected to contain the true value with 95% confidence. To determine the effects of each measurement error, the propagation of uncertainty with all individual uncertainties is used and a Taylor series approximation is used to estimate the uncertainty in this process.

$$\begin{aligned}(\Delta N_{NH_3})^2 = {} & \left(\frac{\partial N}{\partial r_{feed}}\Delta r_{feed}\right)^2 + \left(\frac{\partial N}{\partial W_{feed}}\Delta W_{feed}\right)^2 \\ & + \left(\frac{\partial N}{\partial r_{youngbird}}\Delta r_{youngbird}\right)^2 + \left(\frac{\partial N}{\partial W_{youngbird}}\Delta W_{youngbird}\right)^2 \\ & + \left(\frac{\partial N}{\partial r_{bedding}}\Delta r_{bedding}\right)^2 + \left(\frac{\partial N}{\partial W_{bedding}}\Delta W_{fbedding}\right)^2 \\ & + \left(\frac{\partial N}{\partial r_{marketedbird}}\Delta r_{marketedbird}\right)^2 + \left(\frac{\partial N}{\partial W_{marketedbird}}\Delta W_{marketedbird}\right)^2 \\ & + \left(\frac{\partial N}{\partial r_{mortality}}\Delta r_{mortality}\right)^2 + \left(\frac{\partial N}{\partial W_{mortality}}\Delta W_{mortality}\right)^2 \\ & + \left(\frac{\partial N}{\partial r_{litter}}\Delta r_{litter}\right)^2 + \left(\frac{\partial N}{\partial W_{litter}}\Delta W_{litter}\right)^2\end{aligned}$$

Results and Discussion

The NH_3 emissions as obtained with the CFI method were 869, 872, and 699 kg for three monitored flocks, respectively, with an annual total of 2010 kg NH_3-N. A component error analysis revealed an uncertainty of <10% for the measured emission values under the monitoring conditions.

The new bedding only contributed a small portion (94 kg) to the total N input because of the low N content (0.20-0.28 %) and relative small amount (38,420 kg for all three flocks). There was considerable flock-to-flock variation in body N content of the marketed birds in that it was 2.70% for flock 1 but 3.24 % for flock 3. The body N content of the young birds was relatively constant at 2.32% to 2.63%. The total N inputs from feed, young birds and new bedding were 22,905 kg for the three flocks over the one-year monitoring period. The relative contributions by feed, young birds and new bedding were respectively, 97.5%, 2.1%, and 0.4%. The total N outputs from marketed birds, removed litters, and mortalities were 8144, 8591, and 484 kg, accounting for 47.3% (birds), 49.9% (litter), and 2.8% (mortality), respectively. The calculated difference between N input and output, or by the NMB method, was 6273 kg, which was considered as NH_3-N emission due to negligible N_2O and N_2 emissions. The NH_3-N loss obtained with the NMB method (6273 kg) was three times that (2010 kg) obtained with the CFI method.

Each N input and output component and its associated systematic uncertainty derived from the lab analyses and field records are shown in Tables 2 and 3. Their uncertainty values are assumed to be at a 95% CI level. The relative systematic uncertainties of all variables were set to be 1%, a high standard that corresponded to properly calibrated and maintained scales and analyzers used to weigh samples and analyze the N contents. The uncertainty in total feed N input accounts for the major portion ($96\%=4759^2/ 4858^2$) of the uncertainty in NH_3-N loss. The main cause of this high uncertainty was the high uncertainty (15%) in feed weight. Feed conversion (FC, ratio of feed use to body weight gain) of the three flocks varied from 2.49 to 3.10. It had been observed by the cooperative producer that some feed delivery tickets were mislabeled and the original weight could not be tracked. The large variations in FC among the three flocks reflected these incidents. The marketed birds and removed litters were the remaining contributors to the uncertainty in the NH_3-N loss, 1.3 and 2.7 %, respectively. Contributions by the bedding, young birds, and mortality were rather negligible.

The mean and 95% CI of the NH_3-N loss obtained with the NMB method was 6273 ± 4858 kg (±77% uncertainty), leading to a wide range of 1415 to 11131 kg. In comparison, the NH_3-N emission measured with CFI method was 2010 ± 201 kg (±10% uncertainty). The uncertainty of NH_3-N loss determined with the NMB method could be reduced by applying better sampling and record-keeping strategies to reduce random uncertainty of the component; for example, keeping a solid track of feed weights by using on-site feed bin scales with data logging system and collecting more representative feed samples for each load of feed. The uncertainty of NH_3-N loss could vary from 35.6% to 7.9% when the relative random uncertainty of each component changes from 5% to 1% (Table 1).

Conclusion

Nitrogen mass balance (NMB) over an extended period of time could be used as an alternative way to determine NH_3 emission from animal houses. The production-related data were acquired from the records kept by or presented to the cooperative producer. The results revealed unexpectedly large discrepancy in NH_3-N loss between NMB and the reference concentration-flow-integration (CFI) methods, presumably arising from the large, difficult-to-control uncertainties associated with the NMB components. The outcome of this study cast serious doubt about the adequacy of using nitrogen (N) mass balance for estimating NH_3 emissions from a dynamic production system such as turkey grow-out houses.

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Table 1. Impact of uncertainties in N input and output sources on NH_3-N loss, calculated with N mass balance (NMB) method, for tom turkeys grown from 5 to 20 wk.

N Input or Output Source	Uncertainty		
	5%	2%	1%
Feed, kg	1920	788	427
Bedding. kg	8	3	2
Young birds, kg	41	17	9
Marketed birds, kg	685	281	152
Litter, kg	906	372	202
Mortality, kg	42	17	9
NH_3-N loss per NMB method, kg or %	2232	916	497
	35.6%	14.6%	7.9%

Table 2. Analysis of N input component uncertainty on NH_3-N loss as determined with N mass balance (NMB) method.

			Measurement				95% CI			
	Variable	Unit	Nominal Value	Relative Systematic Uncertainty	Relative Random Uncertainty	N= W_i* R_i	Relative Systematic Uncertainty	Relative Random Uncertainty	Total Relative Uncertainty	Total Uncertainty (kg)
Feed	W1	kg	194585	1%	15.0%	6082	1.4%	30.4%	30.4%	1852
	R1		0.031	1%	2.5%					
	W2	kg	239841	1%	15.0%	6992	1.4%	33.7%	33.8%	2360
	R2		0.029	1%	7.7%					
	W3	kg	326401	1%	15.0%	9831	1.4%	37.6%	37.6%	3695
	R3		0.030	1%	11.3%					
	Total					22905				4759
Bedding	W1	kg	15876	1%	2.0%	32	1.4%	4.5%	4.7%	2
	R1		0.002	1%	1.0%					
	W2	kg	15286	1%	2.0%	42	1.4%	4.5%	4.7%	2
	R2		0.003	1%	1.0%					
	W3	kg	7257.6	1%	2.0%	20	1.4%	4.5%	4.7%	1
	R3		0.003	1%	1.0%					
	Total					94				3
Young birds	W1	kg	5411	1%	5.0%	127	1.4%	13.0%	13.0%	16
	R1		0.023	1%	4.1%					
	W2	kg	6447	1%	5.0%	169	1.4%	13.0%	13.0%	22
	R2		0.026	1%	4.1%					
	W3	kg	8451	1%	5.0%	196	1.4%	13.0%	13.0%	26
	R3		0.023	1%	4.1%					
	Total					492				38
Total N input		kg				23491				4759

W_i = component weight of the i^{th} flock, kg
R_i = ratio of N to total component weight for the i^{th} flock, kg
Relative systematic uncertainty (β) = (systematic error of the measurement methods and instruments) / (mean)
Relative random uncertainty (s) = (standard error of the measurement mean) / (mean)
Total relative uncertainty = $\sqrt{\beta^2 + s^2}$
CI = confidence interval

Table 3. Analysis of N output component uncertainty on NH_3-N loss as determined with N mass balance (NMB) method.

			Measurement				95% CI			
	Variable	Unit	Nominal value	Relative Systematic Uncertainty	Relative Random Uncertainty	N= W_i* R_i	Relative Systematic Uncertainty	Relative Random Uncertainty	Total Relative Uncertainty	Total Uncertainty (kg)
Marketed birds	W1	kg	71168	1%	2.0%	1920	1.4%	11.3%	11.3%	218
	R1		0.027	1%	5.3%					
	W2	kg	96194	1%	2.0%	2820	1.4%	11.3%	11.3%	320
	R2		0.029	1%	5.3%					
	W3	kg	105212	1%	2.0%	3404	1.4%	11.3%	11.3%	386
	R3		0.032	1%	5.3%					
	Total					8144				547
Litter	W1	kg	25012	1%	5.0%	450	1.4%	11.2%	11.3%	51
	R1		0.018	1%	2.5%					
	W2	kg	72721	1%	5.0%	2160	1.4%	15.2%	15.2%	329
	R2		0.030	1%	5.7%					
	W3	kg	200019	1%	5.0%	5981	1.4%	12.2%	12.2%	732
	R3		0.030	1%	3.5%					
	Total					8591				804
Mortality	W1	kg	3751	1%	5.0%	94	1.4%	14.1%	14.2%	13
	R1		0.025	1%	5.0%					
	W2	kg	7954	1%	5.0%	221	1.4%	14.1%	14.2%	31
	R2		0.028	1%	5.0%					
	W3	kg	6048	1%	5.0%	168	1.4%	14.1%	14.2%	24
	R3		0.028	1%	5.0%					
	Total					484				42
Total N output						17218				973

W_i = component weight of the i^{th} flock, kg
R_i = ratio of N to total component weight for the i^{th} flock, kg
Relative systematic uncertainty (β) = (systematic error of the measurement methods and instruments) / (mean)
Relative random uncertainty (s) = (standard error of the measurement mean) / (mean)
Total relative uncertainty = $\sqrt{\beta^2 + s^2}$
CI = confidence interval