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Ammonia emissions from a naturally and a mechanically ventilated broiler house in Brazil

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ABSTRACT

This study was conducted with the aim of monitoring NH_3 emissions from a mechanically and a naturally ventilated broiler house (MVB and NVB, respectively) and calculate their ammonia emission factors (f_{NH3}). Bird stocking density was 13.5 and 11.1 birds m^{-2} for the MVB and NVB, respectively. The marketing age was 43 days and bedding consisted of dried coffee husks in its first time of use. Ventilation rates were calculated with the metabolic carbon dioxide mass balance method. Values of f_{NH3} were 0.32 ± 0.10 and 0.27 ± 0.07 g $bird^{-1}$ d^{-1} for the MVB and NVB, respectively, and are in agreement to what was presented in other studies performed under similar conditions. The f_{NH3} estimated on yearly basis was 58 g $bird\text{-}place^{-1}$ $year^{-1}$. It was concluded that the different types of ventilation system between the studied broiler barns did not significantly affect emissions in the modeling process. The results obtained help providing reliable methodology for the determination of a solid database on NH_3 emission factors for tropical conditions that can be used for future inventories, when performed in a sufficient number of barns that is representative for the Brazilian scenario.

Palavras-chave:
fator de emissão
inventário
taxa de ventilação
condições tropicais

Emissão de amônia de galpões de frangos de corte com ventilação natural e mecânica no Brasil

RESUMO

Este estudo foi conduzido com o propósito de monitorar a emissão de amônia (NH_3) de um galpão de frango de corte com ventilação mecânica e outro com ventilação natural (GVM e GVN, respectivamente) e, por fim, calcular seus fatores de emissão de NH_3 (f_{NH3}). A densidade de alojamento das aves foi 13.5 e 11.1 aves m^{-2} para o GVM e GVN, respectivamente. As aves foram removidas para o abate aos 43 dias e a cama consistiu de casca de café, em primeiro uso. As taxas de ventilação nos galpões foram calculadas com base no método do balanço de dióxido de carbono. Os valores de f_{NH3} obtidos foram 0.32 ± 0.10 e 0.27 ± 0.07 g ave^{-1} d^{-1} para o GVM e GVN, respectivamente, e estão de acordo com o que foi apresentado em outros estudos independentes, realizados em condições similares. O valor estimado de f_{NH3} em base anual foi 58 g $ave\text{-}alocada^{-1}$ ano^{-1}. Concluiu-se que o tipo de sistema de ventilação adotado em cada galpão não afetou, de modo significativo, a parametrização da equação de emissão no processo de modelagem. Os resultados validam a acurácia da metodologia de determinação da emissão de amônia para galpões nas condições brasileiras e contribuem para a formação de base de dados confiável de fatores de emissão em climas tropicais, quando aplicada em um número suficiente de galpões que seja representativo do cenário brasileiro.

INTRODUCTION

At global scale, Brazil is the third biggest producer and first ranked exporter of broiler chicken (MAPA, 2013). However, even with the considerable magnitude of animal production systems, very little effort has been given to estimate ammonia (NH_3) emission factors (f_{NH3}) from poultry houses under the unique Brazilian conditions: tropical climate and non-insulated broiler houses, that can either be mechanically or naturally ventilated (Tinôco, 2001).

Studies on NH_3 emissions from confined animal operations such as broiler housing systems have been carried out around the world since at least 30 years. One of the outcomes of scientific research on NH_3 emissions from animal activity that have become a paradigm in the field is that excess NH_3 in the atmosphere is detrimental to natural ecosystems (Galloway et al., 2008). The countries that first started their emission studies are now at either of the following stages: (1) conducting emissions inventories, (2) developing mitigation techniques and

(3) setting regulations. Emissions of NH_3 are still not legislated in Brazil, even though recent studies conducted in several parts of the world have evidenced changes in N sensitive ecosystems in nearby areas that have intense livestock activity, pointing out the urgent need for implementation of mitigation strategies (Sutton et al., 2008).

In recent years, a few studies on NH_3 emissions conducted in Brazil have evidenced an increasing interest of the scientific sector on that issue. For instance, Miragliotta et al. (2004) reported one of the first studies on the development of a statistical model for NH_3 emissions from Brazilian broiler houses, based on correlation of emissions with variables such as pH, environmental temperature and relative humidity; Lima et al. (2011) presented NH_3 emission factors for mechanically ventilated broiler barns under different litter conditions (new vs. used) combined with different stocking densities; Osorio (2010) developed a practical method for determining NH_3 emission rates in naturally ventilated Brazilian broiler barns; Souza & Mello (2011) presented an attempt of inventory of NH_3 emissions from all domestic animal categories over the state of Rio de Janeiro, however, using emission factors from studies performed in Europe and the U.S.A, and thus under temperate climate conditions. Some effort has also been given on the evaluation of mitigation strategies to reduce Brazilian NH_3 emissions, such as the study reported by Medeiros et al. (2008), who evaluated the effect of chemical additives to the litter as a means to reduce NH_3 volatilization.

However, given the magnitude and variability of Brazilian territorial area and poultry production, the number of studies dedicated to determine NH_3 emissions from this sector is very limited. Furthermore, because the majority of the livestock barns in Brazil are naturally or semi-naturally ventilated, including most poultry barns (Tinôco, 2001; Nazareno et al., 2009; Menegali et al., 2013), specific methodologies for determination of NH_3 emission rates (ER) in these conditions must be developed, to strengthen the existent database on emission factors of this pollutant.

Hence, this study was conducted with the purpose of simultaneously monitoring NH_3 emissions from a typical mechanically and also a typical naturally ventilated Brazilian broiler houses and calculate their ammonia emission factors (f_{NH3}).

MATERIAL AND METHODS

The study was conducted in two commercial broiler barns, one naturally ventilated (NVB) and the other mechanically ventilated (MVB), both located on the same farm in the state of Minas Gerais, Brazil. The MVB had a dimension of 120.0 × 14.0 × 2.5 m (L × W × H), fiber-cement tile roof, and a polyurethane drop ceiling (the same material as used for the sidewall curtains). The sidewall curtains were closed most of the time, and the ventilation was provided with 8 newly installed exhaust fans (specified capacity of 39,329 m^3 h^{-1} each at 1.5 HP and static pressure of 12.0 Pa) placed on the west end of the building. Fresh air was brought into the barn through air inlets located at the east end, and the inlet openings were adjusted manually, as needed. The ventilation program was based on indoor air temperature and consisted of 7 stages including minimum ventilation at the early age of the birds (< 3 week). The barn had an initial placement of 23,100 male Cobbs® chicks (stocking density of 13.5 birds m^{-2}), and freshly dried coffee husks, serving as floor bedding, which was never used to raise broilers before. Chicks were reared up to marketing age of 43 days.

The NVB had the dimension of 75 L × 12 W × 2.75 H m. It was roofed with ceramic tiles and polyurethane drop ceiling (same as used for sidewall curtains). Ventilation was provided through manual opening of the sidewall curtains (fully open, half open, or nearly closed). The initial bird placement was 10,000 female Cobbs® (stocking density of 11.1 birds m^{-2}), and had the same kind of non-used litter described for the MVB. This flock was also reared up to a marketing age of 43 days.

The lighting program was similar for both sex/barns and consisted of 1 hour dark between the ages 2-10 days; then the number of dark hours was increased to 9, and then decreased again to 8, 7 and 6 hours of dark at the ages of 22, 23 and 24 d, respectively. The light schedule then remained the same until bird age was 39 days, from whereon the number of dark hours was set to 5, decreasing one hour a night till pick up day.

Measurements of gaseous concentrations of CO_2 were performed in order to calculate air flow rate throughout the barns through the method proposed by Pedersen et al. (2008) with a hand-held sensor (model AZ 77535 CO_2 concentration, AZ Instrument Corp., Taichung City, Taiwan) that had a measuring range of 0-9999 ppm_v, resolution of 1 ppm_v and accuracy of ± 30 ppm_v ± 5% of the reading (according to specifications and calibrated at the factory). Concentrations of NH_3 were measured with an electrochemical detector "Gas Alert Extreme NH_3 Detector" (BW Technologies®, Oxfordshire, UK), with a measuring range of 0-100 ppm_v, operating temperature of -4 and 40 °C, and accuracy of 2% (at 25 °C and relative humidity between 15 to 90%). Both the CO_2 and NH_3 sensors were calibrated at the factory prior to the start of the study.

For the MVB, background or outdoor CO_2 and NH_3 concentrations were measured at the inlet, nearby the east end of the building while indoor concentrations were measured at the outlet (upstream to the exhaust fans).

For the NVB, indoors gaseous concentrations of CO_2 and NH_3 were measured at three different distances along the central axis of the building (at 18, 36 and 54 m from the eastern extremity of the barn), and at two different heights (0.50 and 1.25 m above the litter). Outdoor concentrations were measured at three different points along the south side of the building, which was considered the air inlet, as during the experimental period the wind was consistently coming from the south.

Data collection of concentrations of CO_2 and NH_3 was done once every three hours, for a 48 hours period, performed weekly throughout the 7 week grow-out period.

Building ventilation rate was estimated through Eq. 1 (Pedersen et al., 2008).

$$Q = \frac{A \cdot (CO_2)_{metabolic} + (CO_2)_{litter}}{\Delta[CO_2]} \qquad (1)$$

where:

Q - building ventilation flow, $m^3\ d^{-1}\ hpu^{-1}$

A - relative animal activity, dimensionless (Pedersen et al., 2008)

$(CO_2)_{metabolic}$ - metabolic CO_2 production by the animals, $m^3\ d^{-1}\ hpu^{-1}$

$(CO_2)_{litter}$ - CO_2 released by the litter, $m^3\ d^{-1}\ hpu^{-1}$

$\Delta[CO_2] = ([CO_2]_{indoors} - [CO_2]_{outdoors})$, the indoor and outdoor CO_2 concentrations, respectively (ppm_v)

Ventilation rates in $m^3\ d^{-1}\ hpu^{-1}$ were then converted in $m^3\ d^{-1}\ bird^{-1}$ by using the conversion factor proposed by Pedersen et al. (2008) of 1 hpu (heat production unit) as 1000 W of total heat at 20 °C. Additionally, a correction factor for metabolic CO_2 production was performed with temperature measurements made in the barns. A more detailed algorithm for the calculation of Q for both buildings was developed and described in the work presented by Mendes et al. (2014).

Daily NH_3ER was calculated with Eq. 2.

$$NH_3ER = \frac{Q \cdot \Delta[NH_3] \cdot W_{NH_3}}{V_{NH_3}} \qquad (2)$$

where

Q - building ventilation flow, $m^3\ d^{-1}\ bird^{-1}$

NH_3ER - ammonia emission rate, g $bird^{-1}\ d^{-1}$

$\Delta[NH_3] = ([NH_3]_{indoors} - [NH_3]_{outdoors})$, the averaged indoor and outdoor NH_3 concentrations, respectively, ppm_v

W_{NH3} - molecular weight of NH_3 (17.031 g mol^{-1})

V_{NH3} - molar volume of NH_3 at standard temperature (25 °C) and pressure (1 ATM, 0.0245 $m^3\ mol^{-1}$)

The mean difference between daily NH_3ER data from the MVB and the NVB obtained simultaneously (measured at the same bird age) was tested with the procedure PROC TTEST in SAS®. The objective of the use of a two sided t-test was to test the hypothesis that the mean difference between NH_3ER from both barns is significantly different from zero.

Furthermore, an analysis of variance was performed at two different levels to test the explanatory power of two models in predicting NH_3ER. The first level consists of a simpler or reduced model, which describes NH_3ER as a function of bird age only, in which data sets from both types of barns were pooled together as is represented by Eq. 3. For the second level, a more complex, or full model is tested, in which the type of barn was included with the development of one regression equation for each, the MVB and NVB, represented by Eqs. 4 and 5, respectively.

Reduced model:

$$NH_3ER = ß_0 + ß_1 \cdot x + ß_2 \cdot x^2 \qquad (3)$$

Full model:

$$NH_3ER_{MVB} = ß_{0,MVB} + ß_{1,MVB} \cdot x + ß_{2,MVB} \cdot x^2 \qquad (4)$$

$$NH_3ER_{NVB} = ß_{0,NVB} + ß_{1,NVB} \cdot x + ß_{2,NVB} \cdot x^2 \qquad (5)$$

where:

NH_3ER, NH_3ER_{MVB} and NH_3ER_{MVB} - NH_3 emission rates combined for both barns, for the NVB and MVB, respectively (g $bird^{-1}\ d^{-1}$)

x - bird age, day (21 d < x < 43 d)

$ß_o$, $ß_1$, $ß_2$, $ß_{o,MVB}$, $ß_{1,MVB}$, $ß_{2,MVB}$, $ß_{o,NVB}$, $ß_{1,NVB}$ and $ß_{2,NVB}$ - empirical coefficients obtained through regression analysis

The ANOVA was performed for each model using the procedure PROC GLM in SAS®. In order to test whether the extra degrees of freedom included in the full model has a significant impact on the estimate of NH_3ER, an extra sum of squares test (Ramsey & Schafer, 2002) was performed from the ANOVA output obtained from each model. Additionally, an analysis of regression was performed with PROC REG in SAS® for the determination of model coefficients.

With the adjusted equation, cumulative NH_3 emission data was calculated throughout a one year period using a methodology similar to that of Gates et al. (2008), by incorporating downtime between flocks and variation in days to achieve market weight, mimicking the effect of multiple flocks in the same barn.

Results and Discussion

Mean f_{NH3} obtained from the MVB and NVB were 0.32 ± 0.10 and 0.27 ± 0.07 g $bird^{-1}\ d^{-1}$, respectively, and are presented in Table 1. The results of the paired t-test indicated that the mean difference in daily NH_3ER measured in the MVB and NVB was 0.05 ± 0.07 g bird d^{-1} and was not significantly different from zero (p = 0.394). This outcome suggests that for the studied MVB and NVB, the use of different ventilation systems (mechanical vs. natural) when combined with different stocking density allocations (13 and 11 birds m^{-2}) did not allow for different ERs.

The daily f_{NH3} obtained from similar studies performed in Brazil and abroad are also presented in Table 1. Unfortunately, not all the emission factors presented in the considered studies were accompanied by an uncertainty estimate, such as a standard error (SE), which makes it difficult to draw comparisons. The emission factor presented by Lima et al. (2011) of 0.78 g $bird^{-1}\ d^{-1}$ was relatively higher than the ones presented in this study, even though the monitoring study performed by those authors also took place in Brazil. The difference might be due to the fact that in the study of Lima et al. (2011) the broiler barns were ventilated with lower mean ventilation rates. Lower levels of air exchange rate enhance conditions for NH_3 volatilization from litter in MVBs, causing, thus, an increase in emission rates. As

Table 1. Ammonia emission factors (f_{NH3}) estimated from this study and other studies

Reference[1]	Type of ventilation system	NH_3ER (mean ± SE[2], g bird^{-1} d^{-1})	Local
This study	Mechanical	0.32 ± 0.10	MG[3]/Brazil
This study	Natural	0.27 ± 0.07	MG/Brazil
Osorio (2010)	Natural	0.28 ± 0.16	MG/Brazil
Lima et al. (2011)	Mechanical	0.78	SP[3]/Brazil
Burns et al. (2007)	Mechanical	0.47	KY[4]/USA
Wheeler et al. (2006)	Mechanical	0.63	KY & PN[4]/USA
Groot Koerkamp et al., (1998)	Mechanical	0.21-0.47	Northern Europe[5]

[1] For comparison purposes, only broiler barns with new litter were considered; [2] Standard error of the mean; [3] Minas Gerais and São Paulo states; [4] Kentucky and Pensylvania states; [5] Denmark, England, Germany and the Netherlands

for a comparison with the f_{NH3} obtained by Osorio (2010), in a study performed inside a NVB, the value of 0.28 ± 0.16 g bird^{-1} d^{-1} was comparable with the values obtained for both barns of this study, this similarity might be due to the fact that the broiler barns from both studies were located in the same state, and presumably having the similar types of management, and feed protein content.

Considering the comparison of f_{NH3} obtained in this study with those obtained in the U.S.A and northern Europe, data in Table 1 indicate that the values obtained from two American studies (Wheeler et al., 2006; Burns et al., 2007) are considerably higher (0.47 and 0.63 g bird^{-1} d^{-1}, respectively). However, data from this study seems to fit well with those presented by Groot Koerkamp et al. (1998) for four northern European countries (Denmark, England, Germany and the Netherlands), varying from 0.21 to 0.47 g bird^{-1} d^{-1}. It is speculated that the emission factors for the U.S.A. are considerably higher than those of Northern Europe and the ones obtained in this study potentially due to reuse of litter over a couple of cycles, while in European farms new litter is used every cycle.

The calculated F-statistics of the regression analysis performed for reduced and full models were higher than the critical F-values for both models at a significance level of 1%, suggesting that both models presented good fit to the experimental data (Table 2).

The test of significance for the coefficients ß$_o$, ß$_1$ and ß$_2$ in Eq. 3 indicated that all of them are significantly different than zero (p-value < 0.001), and results are presented in Table 3. A comparison of the estimates of the coefficients obtained for data from the MVB and NVB (full model) suggest that they are relatively similar to those obtained from the pooled data set (reduced model). For instance, the estimated values for the coefficient respective to the independent term, $\beta_{o,MVB}$ or $\beta_{o,NVB}$, were -4.0 ± 0.6 and -3.2 ± 0.6 g bird^{-1} d^{-1}, respectively, while that obtained from the pooled data sets (β_o) was -3.5 ± 0.4 g bird^{-1} d^{-1}. The estimated coefficient for the squared term (x^2) in Eq. 3 was -0.0040 ± 0.0006 and -0.0028 ± 0.0006 g bird^{-1} d^{-3}, for the MVB and NVB, respectively, against -0.0034 ± 0.0004 g bird^{-1} d^{-3}, obtained when neglecting the type of ventilation system. The similarity between the regression models obtained with the regression for MVB and NVB can be seen with the plots shown in Figure 1A, and regression curve respective to the pooled data sets is presented in Figure 1B.

Table 2. Summary of analysis of variance (ANOVA) for the regression of NH_3 emission rate (NH_3ER, g bird^{-1} d^{-1}) as a function of bird age (x, day) only (reduced model); the regression of NH_3 emission rate against bird age and type of barn (NVB or MVB) (full model)

Parameter	Degrees of freedom	Sum of squares	Mean sum of squares	F
Reduced model	3	6.87	2.29	59.83 **
Residual	111	4.25	0.04	
Total	113	11.12		
Full model	6	7.05	1.17	32.01 **
Residual	111	4.07	0.04	
Total	113	11.12		

**The calculated F-statistic is higher than the critical F-statistic from a F distribution table (Ramsey & Schafer, 2002) at a confidence level of 0.95

Table 3. Results from regression analysis for the relationship between bird age and NH_3 emission rate, according to the type of model (reduced and full)

Parameter*	ß$_0$ (g bird^{-1} d^{-1})	ß$_1$ (g bird^{-1} d^{-2})	ß$_2$ (g bird^{-1} d^{-3})
Reduced model	-3.5 ± 0.4	0.24 ± 0.03	-0.0034 ± 0.0004
Full model: MVB	-4.0 ± 0.6	0.27 ± 0.04	-0.0040 ± 0.0006
Full model: NVB	-3.2 ± 0.6	0.21 ± 0.04	-0.0028 ± 0.0006

*all coefficient estimates were significantly different than zero at a confidence level of 0.95

The negative sign of the coefficient ß$_o$ indicates that the daily NH_3ER increases with bird age, reaching a maximum, and starts to decrease. The behavior of increasing NH_3ER with increase in age can be explained by the fact that the manure accumulated in the new litter gradually starts to release NH_3, only being detected by our NH_3 sensor at x > 21 d. However, the sudden increase in ventilation rate that happened when the birds reached the fifth week of age, as an attempt to keep thermo neutrality conditions in the barns (Figure 1), presumably causing litter moisture content to decrease with consequent reduced volatilization of NH_3, and thus reducing NH_3ER.

Additionally, the results of the extra sum of squares test, performed to compare full and reduced models are presented in Table 4, and indicate that the models are not significantly different in predicting NH_3ER, with a calculated F-statistics (1.55) that is less than the critical F-value (> 3.95). This outcome suggests that the extra complexity represented by the full model with the inclusion of the factor 'type of barn' did not make the model fit better than the reduced to NH_3ER data. For this reason, the full model was discarded and further data analysis and discussion in this paper were done with the data sets from MVB and NVB pooled together.

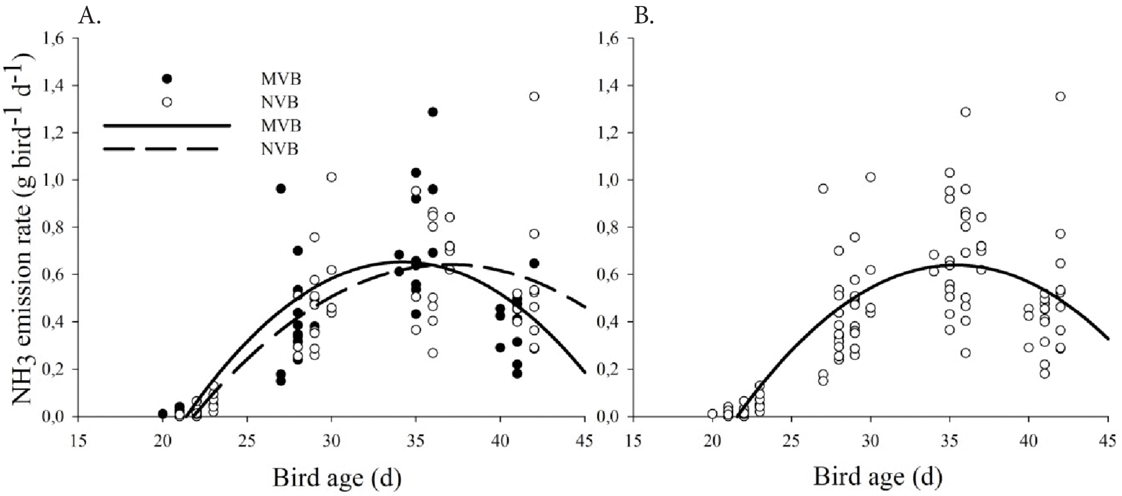

Figure 1. Relationship between bird age and NH_3 emission rate for both the mechanically and naturally ventilated barns (MVB and NVB, respectively) (A) and obtained from pooling data for both types of barns (B)

Table 4. Results from the extra sum of squares test that was performed on the additional degrees of freedoms included by the full model when compared with the reduced model

Parameter	Degrees of freedom	Sum of squares	Mean sum of squares	F
Full vs. Reduced models	3	0.18	0.06	1.55^{ns}
Residual	110	4.25	0.04	
Total	113	4.43		

** the calculated F-statistic is higher than the critical F-statistic from a F distribution table (Ramsey & Schafer, 2002) at a confidence level of 0.95

The adjusted model obtained for the relationship between daily NH_3ER and bird age for the pooled data sets from MVB and NVB were used to calculate cumulative NH_3 emissions throughout an entire cycle of 43 days, and the results are graphically represented in Figure 2, a similar procedure was performed by Gates et al. (2008) for broilers housed in a mechanically ventilated barn with litter of first use and stocked at 15 birds m^{-2}, whose results are also included in Figure 2.

The observation of the curves in Figure 2 suggests that the increase in cumulative NH_3 emissions throughout a complete rearing cycle of 43 days for the barns used in the current study are relatively lower as compared to that of the study performed by Gates et al. (2008). It is speculated that the difference might be due to factors that play an important role on NH_3 emissions such as distinct feed protein content, mean barn ventilation rate and litter reusing practices.

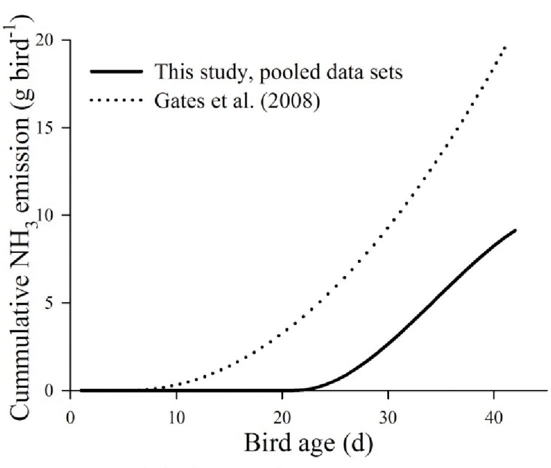

Figure 2. Modeled cumulative NH_3 emission as a function of bird age for data combined from both the mechanically and naturally ventilated barns

In order to estimate f_{NH3} in an yearly basis for the barns monitored in this study, cumulative emissions from multiple flocks throughout a year were calculated using the adjusted equation that resulted from the pooled data set, with coefficients shown in Table 3. In order to comply with the sanitary safety period between flocks, a gap of 14 days between flocks was used. It was assumed that at the start of every flock, only new litter was used, meaning that no NH_3 was emitted during the 14 d sanitary safety period. Similar calculations were performed with data presented by Gates et al. (2008). A graphical representation of the simulated cumulative NH_3 emissions is presented in Figure 3.

Simulated f_{NH3} on yearly basis were 58 g bird-place^{-1} year^{-1}, while the f_{NH3} simulated from the study of Gates et al. (2008) was 141 g bird-place^{-1} year^{-1}. The discrepancy with the yearly f_{NH3} obtained in this study with that from Gates et al. (2008) might have arisen from factors such as differences in farm management, feed protein content offered to the birds and/or distinct mean ventilation rate. Winkel et al. (2011) arrived at 72 ± 25 g bird-place^{-1} year^{-1}, averaged from several monitored mechanically ventilated broiler barns in the Netherlands, this value is much closer to the one obtained in this study than the one obtained from Gates et al. (2008), for the U.S.A. From these results, it is speculated that northern American commercial broilers are fed with very high protein content feed formulas, and the northern European countries, such as the Netherlands, have been implementing feed manipulation techniques to reduce NH_3 emissions as explained before in this paper.

Another important aspect brought up by the study of Winkel et al. (2011) in the calculation of f_{NH3} was the inclusion of a standard deviation to estimate the emission uncertainty

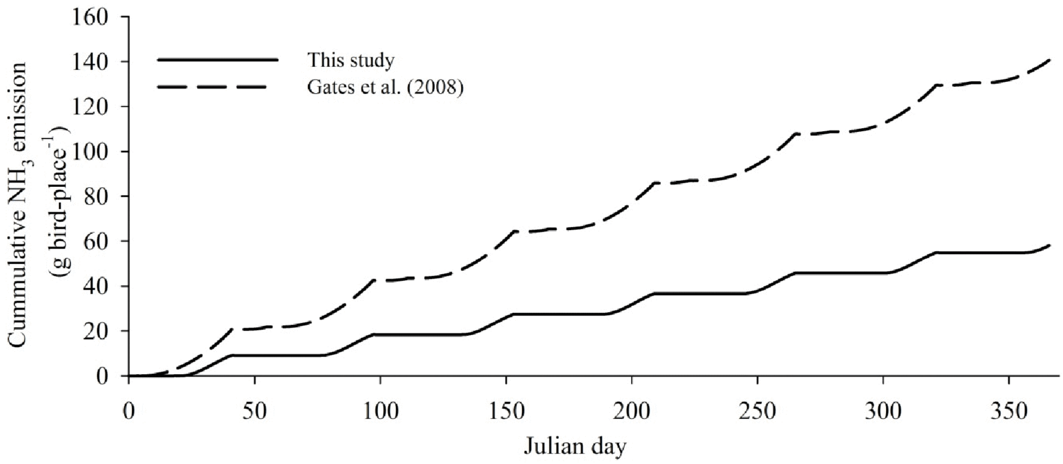

Figure 3. Cumulative ammonia emission over a year, from multiple flocks, averaged for the barns monitored in this study, assuming a resting period between flocks of 14 d

between barns. According to Ogink et al. (2008), including a spatial variability factor (uncertainty between farms) in the determination of f_{NH3} is just as important as considering variability due to seasonal or distinct management system (uncertainty within farm). Hence, it is recommended that the methodology described here be applied to barns located in different farms, so that a measure of uncertainty amongst farms can be included in the calculation of f_{NH3}.

Conclusions

1. The method for determination of NH$_3$ER applicable to both barns, with the ventilation rates being calculated through the CO$_2$ mass balance method, was successful.

2. Estimated values of f_{NH3}, on a daily bases, were 0.40 ± 0.12 and 0.32 ± 0.08 g bird^{-1} d^{-1} for the MVB and NVB, respectively.

3. The types of ventilation system did not have a significant impact on the parameters of the NH$_3$ emission equation, being thus discarded in the modeling.

4. Simulated value of f_{NH3}, on yearly basis, was 58 g bird-place^{-1} year^{-1}.

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