



Dyna

ISSN: 0012-7353

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Colombia

Osorio-Saraz, Jairo Alexander; Ferreira-Tinoco, Ilda de Fatima; Gates, Richard S.; Oliveira-Rocha, Keller Sullivan; Combatt-Caballero, Enrique Miguel; Campos-de Sousa, Fernanda  
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Dyna, vol. 81, núm. 187, octubre, 2014, pp. 137-143

Universidad Nacional de Colombia

Medellín, Colombia

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# Adaptation and validation of a methodology for determining ammonia flux generated by litter in naturally ventilated poultry houses

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Received: November 11th, de 2013. Received in revised form: June 9th, 2014. Accepted: July 22th, 2014

## Abstract

The present work aimed to adapt and validate a precise and simple application method defined as the “Saraz method for the determination of ammonia emissions” (SMDAE), based on the method of mass diffusion, to determine ammonia flux due to mass convection from broiler litter. It was found that ammonia flux (N”A) can be obtained by the SMDAE diffusion method. The SMDAE method presents a recovery efficiency for volatilized ammonia of  $77 \pm 4\%$  and can be used for ammonia concentrations as high as 0.5 ppm.

**Keywords:** Ammonia flux; poultry houses; broiler litter, air quality.

# Adaptación y validación de una metodología para determinar emisiones de amoníaco generado en camas de galpones avícolas con ventilación natural

## Resumen

El objetivo del presente trabajo fue avalar y validar un simple y preciso método definido “método Saraz para determinar emisiones de amoníaco” (SMDAE), basado en un método de difusión de masa, para determinar el flujo de amoníaco debido a la convección de la masa (NA”) generada en la cama aviar. Se encontró que el flujo de amoníaco puede ser obtenido por el método difusivo SMDAE. El método SMDAE presentó una eficiencia en la recuperación del amoníaco volatilizado de  $77 \pm 4\%$  y puede ser usado con concentraciones de amoníaco mayores 0.5 ppm.

**Palabras Clave:** Flujo de amoníaco; instalaciones avícolas; calidad del aire.

## 1. Introduction

Knowledge on ammonia emission rates generated from manure in animal confinements is very important, due to its direct relation to negative health effects and productivity of animals and people [1]. Many studies were performed based on the reduction of ammonia emissions from manure by the minimization of nitrogen excretions in the feces due to dietary changes. This procedure is the first step for reducing NH<sub>3</sub> emissions from agricultural installations [2, 3]. However, despite the efficiencies obtained by the technique

for reducing ammonia by diet manipulation, ammonia emissions cannot be reduced until 100%.

Some methodologies have been developed and validated to determine ammonia gas emissions generated by animal manure, and have been applied in both open and closed animal production installations. However, these obtain different efficiencies in the recovery of the total ammonia nitrogen (TAN), volatilized.

The methodologies most commonly used are those, which involve mass balances, external, and internal tracer gas and the passive methods [4-9].

Most methodologies for ammonia quantification present good performance in closed installations. However, these methods require adaptations for open installations. When using tracer gases, external tracer gases are less efficient compared with internal tracer gases [10,11]. The passive flux method requires predominant air flow in the direction of the flux collector, while the greatest difficulty of the mass balance method is to find the convective mass coefficient [12,13].

Thus, each of the mentioned methodologies has advantages and disadvantages, and a common disadvantage to all is the high cost of operation. Other volatilization models have also been used to predict ammonia emissions based on different circumstances and types of poultry installation [14,15]. The acquisition of mass transfer coefficient ( $h_m$ ), which is an important parameter in the volatilization model of ammonia present in manure, is found in literature with wide variation, and it is a disadvantage of the model.

A methodology used in the study of soils for determining nitrogen (N) loss from the soil by volatilization of TAN makes use of a collector chamber for ammonia fixation by diffusion, where quantification is performed by acid – base titration, using the Kjeldhal method [16]. In this methodology, nitrogen recovery efficiencies of roughly 70% are encountered [17-20].

Based on these facts, the present study aimed to obtain the ammonia flux value due to mass convection ( $N^A$ ) of broiler litter, using the ammonia mass flux (SMDAE) which is based on the mass diffusion method ( $J^A$ ).

## 2. Material and methods

The present study was developed in the Laboratories of the Department of Agricultural Engineering, at the Federal University of Viçosa, Brazil, and in a conventional commercial broiler house working jointly with the Pif-Paf Alimentos S/A company, located in the municipality of Viçosa, MG, Brazil. According to the Köppen classification, the climate of the region is type Cwb – high altitude tropical with wet summers and pleasant temperatures. This study was performed during the summer, with an average temperature of 22°C and relative humidity ranging between 50 and 70%.

### 2.1. Characteristics of the facilities

The commercial poultry house utilized in this investigation housed 14000 Cobb chickens, with housing density of 12 birds  $m^{-2}$  and the following dimensions: 100 m x 13 m (Length x Width), 3 m high ceilings, 0.50 m overhang and 20° roof inclination angle.

The poultry house, with little thermal insulation, which is commonly observed in Brazil and South America, was open with natural ventilation during the experimental phase and the litter was composed of fresh coffee hulls.

### 2.2. Mass diffusion method proposed for determining ammonia mass flux called SMDAE

A passive flux method used by [19] and [21] was adapted and validated for determining ammonia flux from the litter of poultry buildings. This adapted method, called “Saraz method for determination of ammonia emissions”

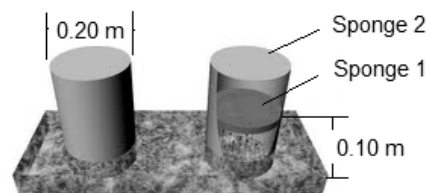


Figure 1. Collector device used to capture volatilized ammonia  
Source: The authors

(SMDAE), is based on the mass diffusion method for the determination of ammonia flux from broiler bedding, based on the total volatilized ammonia content that is volatilized and captured.

#### 2.2.1. Measuring equipment

A common PVC pipe measuring 20 cm in diameter and 30 cm in height was used to construct the  $NH_3$  capturing device. Two polyurethane sponges measuring 20 cm in diameter each and thickness of 2 cm were placed in the tube so that they were 10 cm (Sponge 1) and 30 cm (Sponge 2) from the base of the PVC collector. The function of sponge 1 was to directly capture the ammonia flux produced by the poultry litter bedding, while sponge 2 was used to prevent contamination by exterior gases that might affect the values of the ammonia captured by sponge 1 (Fig. 1).

#### 2.2.2. Appropriate time for ammonia capture

The objective of this experiment was to encounter the ammonia flux from the bed and simulate the natural conditions of this emission in real time, in order to determine the appropriate ammonia adsorption period for the collector device. Thus, the tests performed lasted 1, 2, 3, 4, 12, 16, 22 and 24 hours, with three repetitions for each time.

#### 2.2.3. Location of the collector devices and collection of experimental data

Data collection was performed on three consecutive days in each week of the birds lives, between 22-28, 29-35, and 36-48 days of the productive cycle. In compliance with the studies performed by [6] it was considered that, on the first 14 days, ammonia emissions are minimal and, after this time, emissions increase linearly.

Seeking to observe the influence of waterers and feeders on ammonia flux, compared to other regions of the poultry house, four collector devices were installed in the vicinity of the feeders and four, in the vicinity of the waterers. Ammonia flux measurements were taken during 9 days between 8:00 to 10:00 AM and 3:00 to 5:00 PM.

#### 2.2.4. Determination of the quantity of ammonia captured

To capture volatilized ammonia, each sponge was impregnated with 80 ml of a solution composed of sulfuric acid (1 mol  $L^{-1}$ ) and glycerine (3 %), corresponding to an

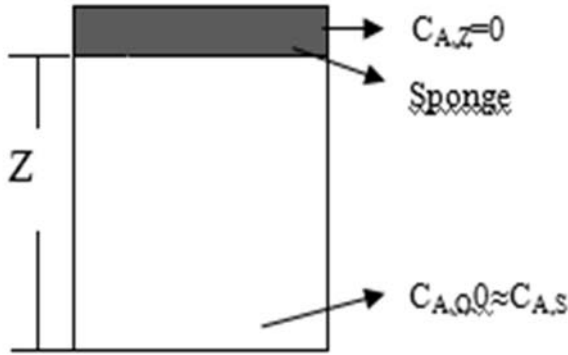


Figure 2. Mass diffusion model of the prototype  
Source: The authors

adaptation of the ammonia fixation method by diffusion, whose quantification is performed by acid-base titration by the Kjeldhal method [16].

Eighty mL of a potassium chloride (KCl) solution at a concentration of  $0.5 \text{ mol L}^{-1}$  added to 40 mL of water were used to extract the ammonia captured in the sponge. This solution mixed with the sponge was prepared in a Tecnal model TE-0363 nitrogen distillation column. After distillation, the condensed sample was titrated with hydrochloric acid (HCl) at a concentration of  $0.5 \text{ mol L}^{-1}$ . The  $\text{NH}_3$  concentration ( $\text{g NH}_3$ ) captured by the sponge was obtained by the volume of the filter solution (mL), the solution concentration ( $\text{mol L}^{-1}$ ), and number of moles of  $\text{NH}_3$ . The SMDAE mass flux was obtained by using the eq. (1).

$$\text{SMDAE} \text{ (g NH}_3 \text{ m}^{-2} \text{ s}^{-1}) = \frac{\text{NH}_3}{At} \quad (1)$$

Where:

SMDAE =  $\text{NH}_3$  mass flux ( $\text{g NH}_3 \text{ m}^{-2} \text{ s}^{-1}$ ).

$\text{NH}_3$  =  $\text{NH}_3$  mass ( $\text{g NH}_3$ ).

A = sponge area ( $\text{m}^2$ ).

t = Exposure time of sponge (s).

### 2.2.5. Determination of the SMDAE efficiency

To determine the efficiency of the proposed SMDAE method for ammonia recovery, it was determined the difference between the quantity of  $\text{NH}_3$  volatilized from the litter and the quantity of  $\text{NH}_3$  recovered by the sponge. Ten replications were performed to achieve this value.

### 2.3. The theoretical proposed SMDAE diffusion method and the mass convection method

The proposed SMDAE diffusion method is derived from Fick's Second Law. A schematic of the prototype is presented in Fig. 2, where  $C_{A,S}$  ( $\text{g m}^{-3}$ ) corresponds to concentration of specie A at the litter bedding surface,  $C_{A,Z}$  ( $\text{g m}^{-3}$ ) concentration at height Z of the sponge;  $J''_A$  that is equal to the ammonia emission flux SMDAE captured by

the sponge ( $\text{g m}^{-2} \text{ s}^{-1}$ ); and  $D_{AB}$  is the diffusion coefficient of ammonia in the air ( $0.28 \times 10^{-4} \text{ m}^2 \text{ s}^{-1}$ ) according to [22].

$$J''_A = \text{SMDAE} = -D_{AB} \frac{\partial C_A}{\partial Z} = \frac{D_{AB} (C_{A,0} - C_{A,Z})}{Z} \quad (2)$$

$$\text{SMDAE} = \frac{D_{AB} C_{A,S}}{Z} \quad (3)$$

For the mass convection model, a boundary limit model was used for concentration of a chemical species on a flat surface, where  $N''_A$  is the ammonia flux ( $\text{g m}^{-2} \text{ s}^{-1}$ ) and  $h_m$  the mass diffusion coefficient. This coefficient is a function of the Reynold's number (Re) and the Schmidt number (Sc); V is the average wind speed at the height of the birds; L is the length of the installation; and  $\nu$  is the viscosity of the air. Mass flux by convection is determined as [22]:

$$N''_A = h_m (C_{A,S} - C_{A,\infty}) \quad (4)$$

For the case in which it is considered outside the boundary limit, mass flux is determined as:

$$N''_A = h_m C_{A,S} \quad (5)$$

Because flow in the building is turbulent, the mass convection coefficient is calculated as:

$$h_m = \frac{D_{AB} 0,0296 \text{ Re}^{\frac{4}{5}} \text{ Sc}^{\frac{1}{3}}}{L} \quad (6)$$

$$0,6 < \text{Sc} < 3000$$

where:

$$\text{Re} = \frac{VL}{\nu} \quad (7)$$

$$\text{Sc} = \frac{\nu}{D_{AB}} \quad (8)$$

Table 1.  
Recovery of volatilized ammonia by the collector device

Ammonia recovered by the sponge ( $\text{g NH}_3 \text{ m}^{-2}$ )	Volatilized ammonia from the litter ( $\text{g NH}_3 \text{ m}^{-2}$ )	Efficiency (%)	Minimum ( $\text{g NH}_3 \text{ m}^{-2}$ )	Maximum ( $\text{g NH}_3 \text{ m}^{-2}$ )
16.76	19.99	$77.55 \pm 4.32$	68.85	82.47

Source: The authors

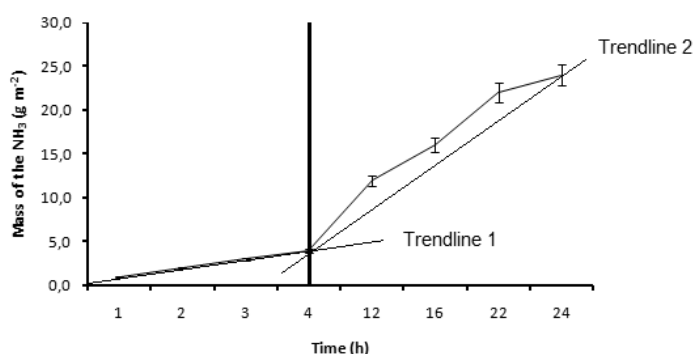


Figure 3. Ammonia mass according to time  
Source: The authors

## 2.4. Statistical analyses

After the experiments, the data obtained from both measurement methods (SMDAE diffusion and convection models ( $N''_A$ )) were treated and analyzed statistically, and a non parametric one-way analysis of variance (Kruskal-Wallis test), with method as treatment, was conducted.

To determine the incidence of variables such as location (waterer and feeder) and the time of the day a non parametric one-way analysis of variance (Kruskal-Wallis test), with period as treatment was conducted.

## 2.5. Acquisition of experimental data

Background ammonia concentration data in the environment were obtained from an electrochemical detector "Gas alert Extreme Ammonia ( $\text{NH}_3$ ) Detector" from BW Technologies with a measuring range from 0-100 ppm, temperature between  $-4$  to  $+40^\circ\text{C}$ , relative humidity from 15% to 90% and presenting an accuracy of  $\pm 2\%$ . Data collection was performed in twenty minutes interval.

Air temperature at sample height was measured (DS1820, Dallas Semiconductor, address). Energy was provided to the 1-wire<sup>TM</sup> system by a parasitic feed derived from the data transmission conductor, where only two conductors are necessary. Temperature measurements were made every five minutes. Air speed ( $\text{m s}^{-1}$ ) was measured with a digital wind gage (Testo 425), with a range between  $0-20 \text{ m s}^{-1}$ , precision of  $\pm 0.5$  ( $^\circ\text{C}$ ), accuracy of 1% (pressure) and 2.5% ( $\text{m s}^{-1}$ ) and  $0.1^\circ\text{C}$ , positioned five centimeters in front of each sponge on the upwind side. Air velocity data collection was performed in five minutes interval. Relative humidity of the air inside and outside of the poultry house was obtained at diverse points representing the entire poultry house, using independent systems (Hobo H8-032) with accuracy of  $\pm 0.7$  at  $21^\circ\text{C}$ . Data collection was performed at one second intervals.

The pH of the poultry litter was determined in the laboratory using a digital pH meter, for which each sample of the bed collected in the installation was diluted in water at a 1:4 ratio (bed sample:water). Moisture content of the litter was determined in the laboratory as the mass difference between

the dry and moist mass using an oven at  $105^\circ\text{C}$ .

## 3. Results and discussion

Fig. 3 presents the behavior of the ammonia mass captured by the collector device encountered by the mass diffusion method in function of the time. It was observed that the behavior of the curve of ammonia for all replicates was linear in function of time, with a greater increase in emissions after the prototype was exposed for four hours. Hence, the prototypes were exposed for no more than two hours to facilitate sampling in the field and allows for a larger numbers of experimental replicates. Table 1 shows the ammonia mass recovery data and the ammonia recovery curve, according to its volatilization. The collector device used had a recovery efficiency of  $77.55 \pm 4.32 \text{ g NH}_3 \text{ m}^{-2}$  and was efficient, compared to the experiments performed by [19, 23] and [21], who found 70% efficiency when using the chamber collector method. Moreover, the proposed method can capture ammonia concentrations exceeding 0.5 ppm.

After determining the efficiency of the collector device, the mass diffusion flux SMDAE was calculated by equation 3. The value of  $C_{A,s}$  was obtained from the SMDAE. The ammonia fluxes were achieved by equation 4, by the mass convection model ( $N''_A$ ).

The mass convection coefficient ( $h_m$ ) was calculated from equation 6 for turbulent flow, temperatures between  $25$  and  $30^\circ\text{C}$ , and velocities at the concentration boundary limit ranging from  $0.10$  to  $0.35 \text{ m s}^{-1}$ , where the values found in this experiment are in agreement with other experiments, including [24] and [25]. The values of  $h_m$  achieved ranged from  $5.15 \times 10^{-4}$  to  $1.34 \times 10^{-3} \text{ m s}^{-1}$ . These  $h_m$  values did not differ from those reported by [26] and [27], who worked with velocities at the same range.

The analysis of variance between the  $N''_A$  and SMDAE method achieved is shown in Fig. 4. The test reveals There was a significant difference between  $\text{NH}_3$  flux values determined by the SMDAE method with the emissions for mass convection obtained by the  $N''_A$  ( $p < 0.001$ ), as expected, due to the incidence of wind in the  $N''_A$  method.

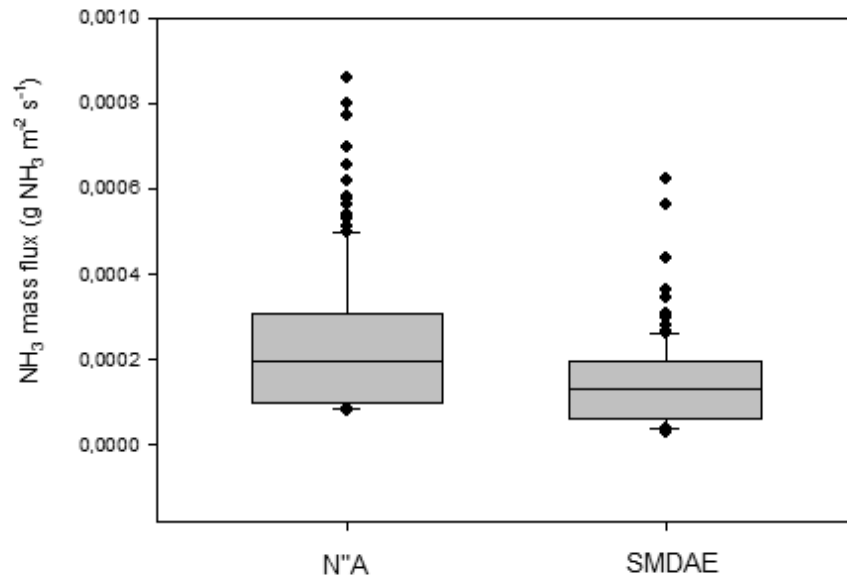


Figure 4. Ammonia flux by the N''A and SMDAE methods  
Source: The authors

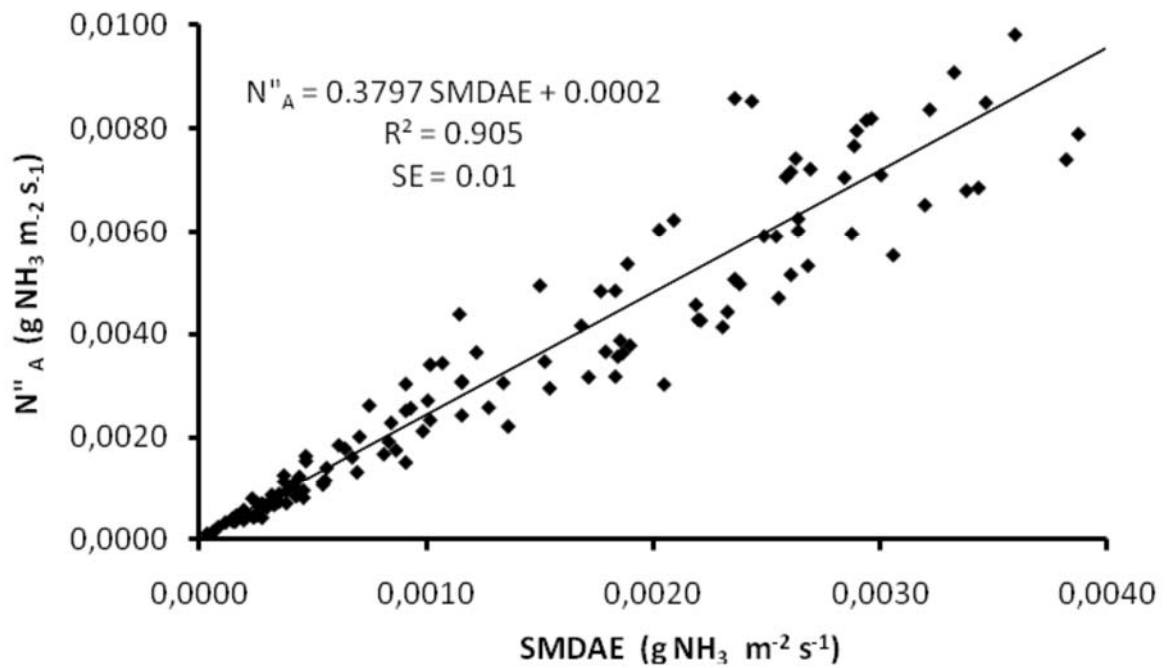


Figure 5. Regression between mass diffusion prototype (SMDAE) and mass convection (N''A)  
Source: The authors

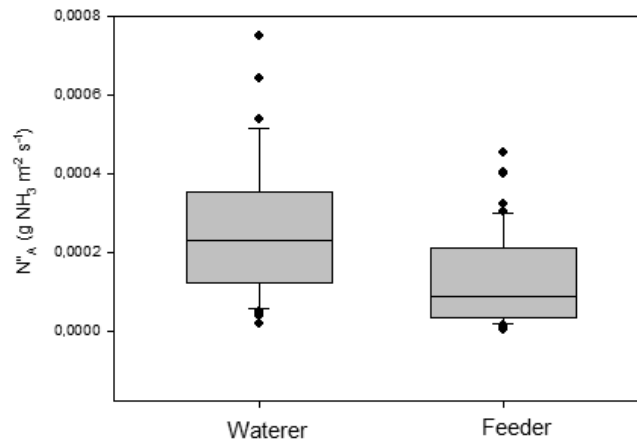


Figure 6. Ammonia flux according to localization  
Source: The authors

Fig. 5 shows the regression of the SMDAE model of mass diffusion and mass convection  $N''_A$ , at the significance level of  $p < 0.05$ . The values of  $N''_A$  underestimate the SMDAE in all cases, as demonstrated in Fig. 4. However, it was observed that the  $R^2$  coefficient was 0.91, which reveals a high correlation between the models and that the SMDAE method can be used to determine  $N''_A$  from poultry manure in terms of natural ventilation. The values of  $N''_A$  within the range  $10^{-5}$  and  $10^{-3} \text{ gNH}_3 \text{ m}^{-2} \text{ s}^{-1}$  did not differ from those reported by [13, 27, 28, 29], who worked with mass transfer methods.

The boxplot of the Fig. 6 show the statistical analysis for the correlation between the convective mass flux ( $N''_A$ ) in function of the location of the samples (waterer and feeder). Results of the analysis of variance at the confidence level showed that There were significant differences ( $p < 0.001$ ). The difference in ammonia flux ( $N''_A$ ) from the litter in the areas of the feeders and waterers may be due to the lower moisture content near the feeders in comparison with the waterers. This was expected, since, according to [28, 30], the total volatilized ammonia (TAN) increases when the moisture of the litter bedding increases.

#### 4. Conclusions

The SMDAE method has a good relationship with the  $N''_A$  mass convection method, which is the method most commonly used for works with mass balances from ammonia sources, and presented a recovery efficiency of approximately 78% of total volatilized ammonia, and can capture ammonia at concentrations as high as 0.5 ppm. Therefore, this method could be considered efficient and used as an alternative to determine ammonia flux ( $N''_A$ ) from the poultry litter in installations with natural ventilation.

#### Acknowledgements

The authors are thankful to the National University of Colombia for this great opportunity; Colciencias-Colombia; the Brazilian Government Agency FAPEMIG; the National Counsel of Technological and Scientific Development (CNPq

- Brazil) and Federal agency CAPES, for their financial support; and the Federal University of Viçosa (UFV-Brazil).

#### References

- [1] Tinoco, I.F.F., A Granja de Frangos de Corte. In: Mendes, A.A.; de Alencar-Naas, I.; Macari, M., (Eds.), *Produção de Frangos de Corte*. 1 ed. Campinas – SP, 2004. pp. 1-345.
- [2] Panetta, D.M., Powers, W.J., Xin, H., Kerr, B.J. and Stalder, K.J., Nitrogen excretion and ammonia emissions from pigs fed modified diets. *Journal of Environmental Quality*, 35 (4), pp. 1297–1308, 2006.
- [3] Ndegwa, P.M., Hristov, J., Arogo E.R. and Sheffield, E., A review of ammonia emission mitigation techniques for concentrated animal feeding operations, *Biosystems Engineering*, 100 (4), pp. 453-469, 2008.
- [4] Welford, E.L., Stéphane, B.E., Lemay, P., Barber, M. and Godbout, S., Simulation of ammonia emissions from swine manure for various diet formulations. In: *CSAE/SCGR Meeting Montréal*, pp. 6 – 9, 2006.
- [5] Nicholson, F.A., Chambers B.J. and Walker, E.A.W., Ammonia Emissions from broiler litter and laying hen manure management systems, *Biosystems Engineering*, 89 (2), pp. 175-185, 2004.
- [6] Gates, R.S., Xin, H., Casey, K.D., Liang, Y. and Wheeler, E.F., Method for measuring ammonia emissions from poultry houses, *J. Applied Poultry*, 14 (1), pp. 622-634, 2005.
- [7] Reidy, B., Mmggen, D.A., Hler, D.H., Eurichmenden, B., Van Evert, F.K., Hutchings, N.J., Luesink, H.H., Menzi, H., Misselbrook, T.H., Monteny, G.J. and Webb, J., Comparison of models used for national agricultural ammonia emission inventories in Europe: Liquid manure syst., *Atmospheric Environment*, 42 (14), pp. 3452–3464, 2008.
- [8] Osorio J.A., Tinoco, F.F. and Ciro H.J., Ammonia: a review about concentration and emission models in livestock structures, *DYNA*, 76 (158), pp. 89-99, 2009.
- [9] Osorio, J.A., Tinoco, I.F.F., Gates, R.S., Oliveira, M.P. and Mendes, L.B., Evaluation of different methods for determining ammonia emissions in poultry buildings and their applicability to open facilities, *DYNA*, 80 (178), pp. 51-60, 2013.
- [10] Dore, C.J., Jones, B.M.R., Scholtens, R., Veld, J.W.H.H.I.T., Burgess, L.R. and Phillips, V.R., Measuring ammonia emission rates from livestock buildings and manure stores, Part 2: Comparative demonstrations of three methods on the farm, *Atmospheric Environment*, 38 (19), pp. 3017-3024, 2004.
- [11] Phillips, V.R.; Scholtens, R., Lee, D.S., Garland, J.A. and Sneath, R.W., SE-Structures and Environment: A review of methods for measuring emission rates of ammonia from livestock buildings and slurry or manure stores, Part 1: Assessment of basic approaches. *Journal of Agricultural Engineering Research*, 7 (4), pp. 355-364, 2000.

- [12] Keener, H.M. and Zhao, L., A modified mass balance method for predicting NH<sub>3</sub> emissions from manure N for livestock and storage facilities, *Biosystems Engineering*, 99 (1), pp. 81-87, 2008.
- [13] Teye, F.K and Hautala, M., Adaptation of an ammonia volatilization model for a naturally ventilated dairy building, *Atmospheric Environment*, 42 (18), pp. 4345-4354, 2008.
- [14] Arogo, J., Westerman, P.W. and Liang, Z.S., Comparing ammonium ion dissociation constant in swine anaerobic lagoon liquid and deionized water, *Transactions of the ASAE*, 46 (5), pp. 1415-1419, 2003.
- [15] Pinder, R.W., Pekney, N.J., Davidson, C.I. and Adams, P.J., A process-based model of ammonia emissions from dairy cows: Improved temporal and spatial resolution, *Atmospheric Environment*, 38 (9), pp. 1357-1365, 2004.
- [16] Association of Official Analytical Chemists – AOAC, *Official methods of analysis*. 11. Ed., Washington D.C, 1015 P, 1970.
- [17] Yang, P., Lorimor, J.C. and Xin, H., Nitrogen losses from laying hen manure in commercial high-rise layer facilities, *Transactions of the ASAE*, 43 (6), pp. 1771-1780, 2000.
- [18] Sangoi, L., Emani, P., Lech, V. and Rampazzo, C., Volatilization of N-NH<sub>3</sub> influenced by urea application forms, residue management and soil type in lab conditions, *Ciência Rural*, 33 (4), pp. 687-692, 2003.
- [19] Renata, H., Cazetta J. and Moraes V.M., Frações nitrogenadas, glicídicas e amônia liberada pela cama de frangos de corte em diferentes densidades e tempos de confinamento, *Rev.bras. zootec*, 3 (4), pp. 1795-1802, 2002.
- [20] Leal, V.L.A., Salamanca, J.A. and Sadeghian, S., Pérdidas de nitrógeno por volatilización en cafetales en etapa productiva, *Cenicafé*, 58 (3), pp. 216-226, 2007.
- [21] Araujo, E.S., Marsola, T., Miyazawa, M., Boddey, R.M., Urquiaga, S. and Rodrigues, B.J., Câmara coletora para quantificação do N-NH<sub>3</sub> volatilizado do solo. In: XXXI Congresso Brasileiro de Ciência do Solo., Gramado RS – Brasil, pp. 1-6, 2007.
- [22] Incropera, F.P. and Dewitt, D.P., *Fundamentals of heat and mass transfer*. Wiley, New York. pp. 344-369, 1999.
- [23] Renata, H. and Cazetta, J., Método simples para determinar amônia liberada pela cama aviária, *Rev.bras. zootec*, 30 (3) pp. 824-829, 2001.
- [24] Brewer, S.K. and Costello, T.A., In situ measurement of ammonia volatilization from broiler litter using an enclosed air chamber, *Transaction of ASAE*, 42 (5), pp 1415-1422, 1999.
- [25] Menegali, I., Tinôco, I.F.F., Baêta, F.C., Cecon, P.R, Guimarães, M.C.C. and Cordeiro, M.B., Ambiente térmico e concentração de gases em instalações para frangos de corte no período de aquecimento, *Revista Brasileira de Engenharia Agrícola e Ambiental*, 13 (10), pp. 984-990, 2009.
- [26] Ni, J., Mechanistic models of ammonia release from liquid manure: a review, *J. Agric. Eng Res*, 72 (1), pp. 1-17, 1999.
- [27] Liu Z.L., Wang, D.B. and Beasley, S.S.B., Modelling ammonia emissions from broiler litter at laboratory scale, *Transactions of the ASABE*, 52 (5), pp. 1683-1694, 2009.
- [28] Miragliotta, M.Y., Avaliação dos níveis de amônia em dois sistemas de produção de frangos de corte com ventilação e densidade diferenciados. Teses. Faculdade de Engenharia Agrícola, Universidade Estadual de Campinas, Campinas, Brasil, 2001.
- [29] Redwine, J.S., Lacey, R.E., Mukhtar, S. and Carey, J.B., Concentration and emissions of ammonia and particulate matter in tunnel-ventilated broiler houses under summer conditions in Texas, *Transactions of ASAE*, 45 (4), pp. 1101-1109, 2002.
- [30] Jones, T.A., Donnelly, C.A. and Dawkins, M.S., Environmental and management factors affecting the welfare of chickens on commercial farms in the United Kingdom and Denmark stocked at five densities, *Poultry Science*, 84 (8), pp. 1155-1165, 2005.

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