

## Model-predicted ammonia emission from two broiler houses with different rearing systems

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**ABSTRACT:** Ammonia (NH<sub>3</sub>) emissions from broiler production can affect human and animal health and may cause acidification and eutrophication of the surrounding environment. This study aimed to estimate ammonia emissions from broiler litter in two systems of forced ventilation, the tunnel ventilation (TV) and the dark house (DH). The experiment was carried out on eight commercial broiler houses, and the age of the birds (day, d), pH and litter temperature were recorded. Broilers were reared on built-up wood shaving litter using an average flock density of 14 bird m<sup>-2</sup>. Temperature and relative humidity inside the broiler houses were recorded in the morning during the grow-out period. A factorial experimental design was adopted, with two types of houses, four replicates and two flocks with two replicates each. A deterministic model was used to predict ammonia emissions using the litter pH and temperature, and the day of grow-out. The highest litter temperature and pH were found at 42 d of growth in both housing systems. Mean ambient air temperature and relative humidity did not differ in either system. Mean model predicted ammonia emission was higher in the DH rearing system (5200 mg NH<sub>3</sub> m<sup>-2</sup> h<sup>-1</sup> at 42 d) than in the TV system (2700 mg NH<sub>3</sub> m<sup>-2</sup> h<sup>-1</sup> at 42 d). TV presented the lowest mean litter temperature and pH at 42 d of growth. In the last week of the broilers' grow-out cycle, estimated ammonia emissions inside DH reached 5700 mg m<sup>-2</sup> h<sup>-1</sup> in one of the flocks. Ammonia emissions were higher inside DH, and they did not differ between flocks. Assuming a broiler market weight in Brazil of close to 2 kg, ammonia emissions were equivalent to 12 g NH<sub>3</sub> bird-marketed<sup>-1</sup>. Model-predicted ammonia emissions provided comprehensible estimations and might be used in abatement strategies for NH<sub>3</sub> emission.

**Keywords:** noxious gases, environmental impact, dark house, poultry, tunnel ventilation

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### Introduction

Agriculture contributes significantly to the anthropogenic emissions of ammonia and greenhouse gases (UNFCCC, 1997; Beusen et al., 2008). As the world's demand for food from livestock production increases, so do the effects of ammonia on rearing surroundings and the atmosphere (Bouwman et al., 1997). Ammonia (NH<sub>3</sub>) emission is the process of NH<sub>3</sub> emission from litter to air, and it may cause eutrophication in the environment (UNFCCC, 1997). Ammonia emissions from poultry houses are a function of the NH<sub>3</sub> concentration inside the housing, which is related to rearing flock density, quality of litter, birds' diet and ventilation system (Gates et al., 2005; Ndegwa et al., 2008; Harper et al., 2010; Menegali et al., 2012).

Ammonia emission estimates are needed to assess the broiler industry's impact on local and regional air quality, particularly in countries that are cosigners of the Kyoto protocol. There are limited scientific estimates of NH<sub>3</sub> emissions from Brazilian broiler facilities. Broiler houses are similar throughout the country. However, the differences in building dimensions and ventilation systems may affect the environmental control of changing the NH<sub>3</sub> emission rate (Wheeler et al., 2006; Gates et al., 2008; Ngwabie et al., 2010). The availability of credible NH<sub>3</sub> emission measurements is very limited due to the high number of variables that influence emissions from broiler

housing (Gates et al., 2008; Snoek et al., 2014). Full-scale *in situ* measurements are costly and time-consuming, and their accuracy might be compromised by variations in the final broiler market weight (Gates et al., 2008).

Field estimations of poultry NH<sub>3</sub> emissions have already been calculated in some countries (Groot Koerkamp et al., 1998; Demmers et al., 1999; Guiziou and Béline, 2005; Pescatore et al., 2005; Wheeler et al., 2006; Gates et al., 2008; Harper et al., 2009; Calvet et al., 2011). Emissions per bird are suggested to be correlated with bird age and litter condition (Groot Koerkamp et al., 1998; Wheeler et al., 2006; Gates et al., 2008), but the results are highly variable (Wheeler et al., 2006; Casey et al., 2010). Mechanistic and deterministic algorithms have been used to estimate NH<sub>3</sub> emissions from animal housing under particular circumstances (Bouwman et al., 1997; Miragliotta et al., 2004; Gates et al., 2005; Siefert and Scudlark, 2008; Casey et al., 2010). The estimation of ammonia shows high variability influencing the predictive emission models (Snoek et al., 2014), and found values have been adopted to define NH<sub>3</sub> emission inventories in different regions and countries (Groot Koerkamp et al., 1998; Demmers et al., 1999; Wheeler et al., 2006; Gates et al., 2008; Harper et al., 2009; Harper et al., 2010; Calvet et al., 2011).

This study aimed to estimate NH<sub>3</sub> emissions in two broiler houses during the grow-out cycle using a predictive model.

## Materials and Methods

### Birds, housing and husbandry

The study was carried out in eight commercial broiler houses located at longitude 54° 11' 6" W and latitude 23° 28' 26" S from March to May, 2013. Birds from the Hubbard® genetic strain were reared in mixed flocks (male and female) for 42 d (market age). In the tunnel system (TV, Figure 1A), 25200 broilers were reared, and 31500 broilers were raised in the dark house system (DH, Figure 1B). The adopted average flock density was 14 bird m<sup>-2</sup> in TV and DH. The bedding in both houses was 10 cm of build-up wood shavings reused by the third time. The houses were east-west solar oriented.

Four houses had the TV system and four the DH system. TV houses (12 m wide, 150 m long and 3.2 m high, and a floor area of 1800 m<sup>2</sup>) had forced ventilation, exhaust fans (11 with air flow of 450 m<sup>3</sup> s<sup>-1</sup>), a high-pressure fogging system and the lateral areas were closed off with yellow polypropylene curtains. DH houses (15 m wide, 150 m long and 3.8 m high, and a floor area of 31500 m<sup>2</sup>) had forced ventilation; exhaust fans (12 with air flow of 580 m<sup>3</sup> s<sup>-1</sup>), a high-pressure fogging system, and internal built walls painted with a black coating. In both houses the chick heating system used during day 1

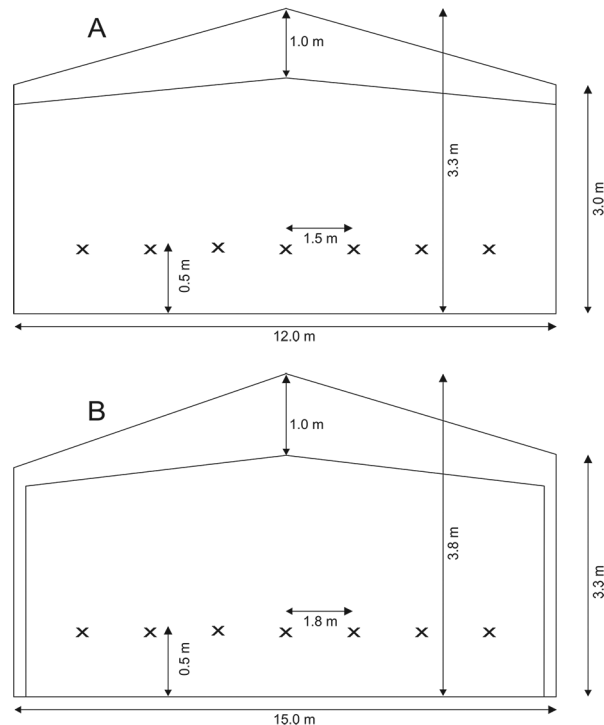


Figure 1 – Schematic dimensions of the tunnel ventilated commercial broiler houses (TV, A and DH, B). Each "x" marks a location where dry bulb ambient temperature and air relative humidity were recorded. Samples of litter temperature and pH were collected on the place projecting this same location on the floor totaling 28 sampling points (7 in each quadrant).

to 14 of the grow-out period consisted of a stove (burned wood) with the heat distributed through metallic tubes with sensors controlling the inlet air temperature. Light intensity inside the houses was set at 25 lx for the first weeks of grow-out (7-21 d), and at 5 lx for the remainder of the grow-out cycle (42 d) using automatic light control based sensors placed in the houses. The two systems had similar ventilation systems with the air inlet at one end, and the outlet at the opposite side. They differed in the reflectivity inside, as the inside walls in the DH houses were coated with black paint.

Ambient air temperature was controlled automatically using the association of the evaporative cooling system and negative pressure ventilation. The air flow was programmed to decrease air temperature from 32 °C on the first day to 27 °C after two weeks, and finally to 24 °C during the end of the grow-out phase.

### Data recording

Air temperature (AT, °C) and relative humidity (RH, %) were measured in the morning (10h00) in the houses using sensors equally distributed over 28 points during the grow-out cycle (Figure 2). Litter pH and temperature (LT, °C) were recorded at the same time using a portable meter. Data recording in areas nearby or below drinkers and feeders were avoided. The age of birds was computed in days (d).

Ammonia emissions were assessed in the area near the air outlet of the houses using the capsule method suggested by Jeppsson (1999) at 21, 35 and 40 d of the grow-out cycle. The methodology allows for estimating the amount of ammonia emissions in a particular area of the litter. The closed cubic capsule had an air inlet using a PVC tube ( $\Phi$  0.075 m) and inside it a small fan (12V, 60mA) was placed to promote homogeneity in the capsule's inside air. The air outlet had a small exhaust fan (maximum flow of 90 m<sup>3</sup> h<sup>-1</sup>) adjusted with a dimmer. The samples of ammonia concentration were taken at a height of 1 m at a point in the PVC tube, after allowing the capsule to be under continuous flow for 20 min in the same place. Ammonia concentrations were measured using a gas pump. Ammonia emissions were measured using a gas pump. Ammonia emissions ( $\epsilon$ , mg m<sup>-2</sup> h<sup>-1</sup>) were estimated using Equation 1 (Jeppsson, 1999).

$$\epsilon = (C_{\text{caps}} - C_2) \sigma \varphi \quad (1)$$

in which  $C_{\text{caps}}$  = ammonia concentration inside the capsule (ppm),  $C_2$  = ammonia concentration at 2 m of height (ppm),  $\sigma$  = the corrected density of ammonia at the capsule outlet (0.765 kg m<sup>-2</sup>), and  $\varphi$  = air flow (m<sup>3</sup> m<sup>-2</sup> h<sup>-1</sup>).

### Model-prediction of ammonia emission

Mean values of recorded variables were calculated, and they were used as input to the software developed using the deterministic algorithm described in Equation 2 (Miragliotta et al., 2004).

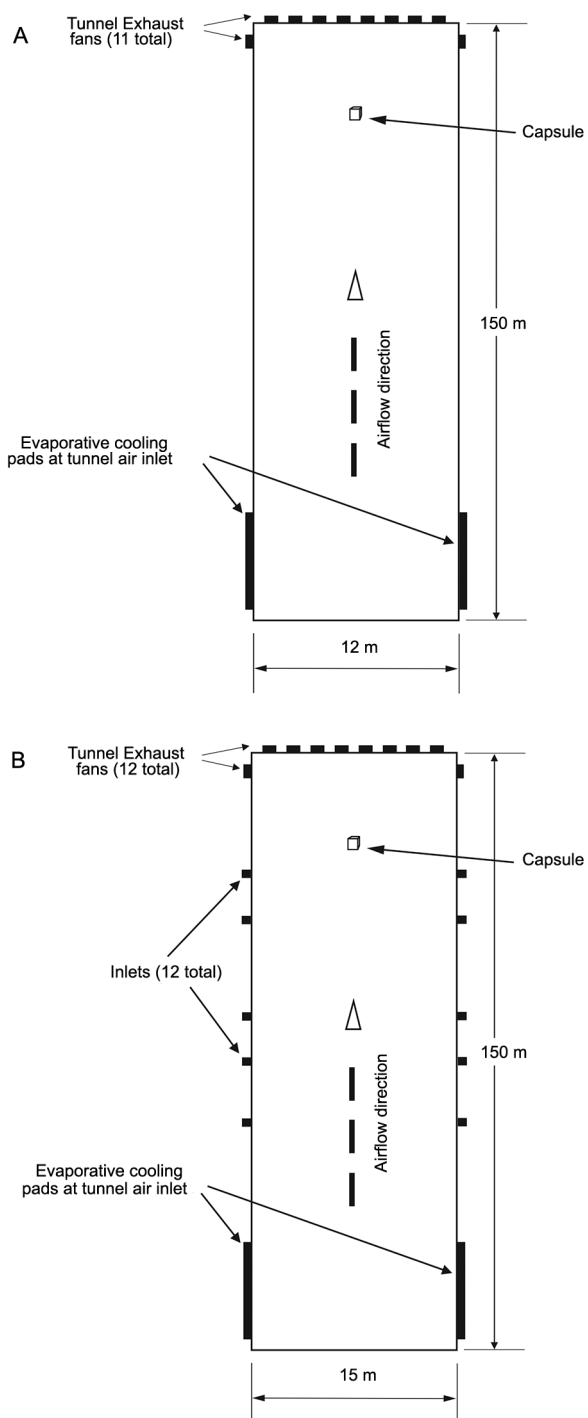


Figure 2 – Schematic plan view of the tunnel ventilated broiler houses TV (A) and DH (B) used in the study.

$$E = \exp (-6.502 + 0.302 d + 0.122 LT + 0.614 pH - 0.004 d^2) \quad (2)$$

in which E = model-predicted ammonia emission ( $\text{mg m}^{-2} \text{h}^{-1}$ ), d = day of grow out, LT = mean litter temperature ( $^{\circ}\text{C}$ ), and pH = litter pH.

### Statistical analysis

The experimental design was completely randomized in a  $2 \times 4$  factorial design (TV and DH; ages 7, 21, 35 and 42 d of growth) with four replicates per treatment, totaling 32 experimental units. The Kolmogorov-Smirnov test was used to verify the hypothesis of normality for all variables, using a 95 % confidence limit. Analysis of variance was used to compare means using the Tukey and the F-test at a 95 % confidence level. For the model-predicted ammonia emission, a  $2 \times 2$  factorial design was adopted, considering the type of the broiler house (TV and DH) and two replications for the number of flocks. All statistical analysis was carried out according to Wheeler and Cook (2000) using ASSISTAT® software (Assistat-Statistical Attendance Software, version 7.6).

### Results and Discussion

The Kolmogorov-Smirnov test showed a normal distribution of the data. An effect of the type of house (factor, F1) or age of birds (F2) was found ( $p > 0.05$ ) in the ambient air temperature and relative humidity only at 35 d ( $p = 0.1$ ; Table 1). Environmental data inside the houses did not differ, indicating that the chosen variables should not be the cause of possible variation in the estimation of  $\text{NH}_3$  emissions. Ambient air temperature is considered a primary factor in regulating the chemical processes involved in ammonia emissions (Wheeler et al., 2006; Sommer et al., 2006; Casey et al., 2010). Previous studies showed that the distribution uniformity of environmental features may affect broiler weight gain (Miragliotta et al., 2006; Lima et al., 2011).

TV houses had lower mean values of LT and pH ( $30.0^{\circ}\text{C}$  and 8.4, respectively) than DH houses ( $33.3^{\circ}\text{C}$  and 8.6, respectively), Table 2. The factor age of broilers presented the highest mean amount at the end of the grow-out cycle (42 d). The distribution uniformity of environmental features may affect broiler weight gain (Miragliotta et al., 2006; Lima et al., 2011). The mean pH values of the two houses (TV and DH) showed a slight difference from the 7 d (8.2) to 42 d of growth. In the present study litter pH was 8.9 in the DH houses and 8.8 in the TV houses at 42 d of grow-out.

Table 1 – Analysis of variance using factors applied to litter temperature (LT), litter pH, ambient air temperature (AT) and relative humidity (RH).

Factor	F (LT)	F (pH)	F (AT)	F (RH)
House (F1)	42.82**	7.53*	0.29 ns	3.60 ns
Age of birds (F2)	12.44**	18.46**	140.24**	6.34*
Int. F1 $\times$ F2	1.35 ns	0.56 ns	2.30 ns	3.11*
Treatment	12.03**	9.23**	61.13**	4.56**
Standard deviation	2.73	0.31	2.99	8.27
Coefficient of variatio (%)	5	2	3	9

\*\*significant at 1 % of confidence ( $p \leq 0.01$ ) F – value; \*significant at 5 % of confidence ( $0.01 \leq p < 0.05$ ) F – value; ns = non-significant ( $p > 0.05$ ).

An important aspect of ammonia emission is the litter characteristics (Groot Koerkamp et al., 1998; Gates et al., 2008). Excreta accumulation on litter increases the litter pH and leads to a rise in  $\text{NH}_3$  concentrations inside broiler houses (Wheeler et al., 2006). The higher the litter pH, the lower the conversion of  $\text{NH}_3$  (volatile) into  $\text{NH}_4^+$  (nonvolatile). Consequently, high ammonia volatilization in built-up litter without proper management is usual (Kristensen et al., 2000). The dark house presented higher litter temperature than the tunnel ventilation system and the ammonia emission in the DH should be greater than in the TV system (Table 2). Broiler housing presents a broad range of  $\text{NH}_3$  emission rates depending on the flock harvest day and the ambient temperature during the grow-out period (Guiziou and Béline, 2005; Wheeler et al., 2006).

$\text{NH}_3$  emissions increased with bird age (Figure 3), which corroborates previous studies (Wheeler et al., 2006; Calvet et al., 2011; Lin et al., 2012). Ammonia emissions increased with broiler growth due to the consequent excreta build-up (Ngwabie et al., 2010; Calvet et al., 2011). There is a strong association between emissions, bird age, and litter condition (Gates et al., 2008; Casey et al., 2010). Broilers were reared on built-up litter, which is known to increase  $\text{NH}_3$  emissions. Gates et al. (2008) and Lima et al. (2011) assessed the ammonia emissions in tunnel ventila-

tion houses and found lower rates of  $\text{NH}_3$  emission in new bedding than in those with built-up litter. However, the renewal of bedding in each flock is not used by farmers as it may lead to an increase in production costs.

Mean values of ambient AT did not differ ( $p > 0.05$ ) and varied according to broiler requirements in each grow-out period (Table 2). The values were 26.4 °C in TV and 26.3 °C in DH. Mean values of RH did not differ between houses; however, an interaction between the "house" and "age of broilers" factors was identified at 35 and 42 d of growth. The change in pH depends on the age of the birds, and it may be attributed to the effect of litter temperature, ambient temperature and density of birds (Pescatore et al., 2005; Menegali et al., 2012). The pH of litter also influences the release of ammonia, which is maximized at levels of pH above 7.0. The difference between the temperature and litter pH at different ages provided a growing impact on the degradation reaction of nitrogen compounds in poultry litter and tended to be alkaline. The increase in temperature and pH of the litter provided greater microbial activity and the formation of noxious gases (Calvet et al., 2011). Thus, the quantity and quality of litter affect the ability of  $\text{NH}_3$  emissions from broiler housing (Toghyani et al., 2010).

The provision of minimum ventilation in the most uniform way is essential to ensuring good air quality control inside broiler housing. The small air exchange, high humidity, temperature and pH, and type of litter management may induce greenhouse gas emissions (Menegali et al., 2012).

Table 2 – Mean values of litter temperature (LT) and pH, ambient air temperature (AT) and relative humidity (RH) inside the aviaries during the total grow out time.

Factor	Flock density (bird m <sup>-2</sup> )	Age of broilers (day, d)				Mean
		7	21	35	42	
		Litter temperature (LT, °C)				
TV	14	29.0	29.0	30.1	31.7	30.0 b
DH	14	32.5	31.2	33.0	36.7	33.3 a
Mean		30.7 b	30.1 b	31.5 b	34.2 a	-
CV (%)		5				
		pH				
TV	14	8.0	8.3	8.5	8.8	8.4 b
DH	14	8.4	8.5	8.6	8.9	8.6 a
Mean		8.2 c	8.4 bc	8.6 b	8.8 a	-
CV (%)		2				
		Air temperature (AT, °C)				
TV	14	30.6	27.5	25.1	22.8	26.4 a
DH	14	30.9	26.5	24.3	23.4	26.3 a
Mean		30.6 a	27.0 b	24.7 c	23.1 d	-
CV (%)		2.98				
		Air relative humidity (RH, %)				
TV	14	76 aA	73 aA	60 aB	80 aA	72 a
DH	14	73 aA	66 aA	66 aA	68 bA	68 a
Mean		75 a	70 ab	63 b	74 a	-
CV (%)		9				

Tukey test was applied. Mean values followed by the same letter did not differ ( $p > 0.05$ ). For RH, mean values followed by the same letter in the column (lower case) do not differ. Different letters in the same row (upper case) are different ( $p \leq 0.05$ ). CV = Coefficient of variation; TV=tunnel ventilation; DH=dark house.

### Model-predicted ammonia emissions

Mean ammonia emission amounts measured inside the TV using the capsule were similar for both houses studied at the first stage of the grow-out cycle (Figure 4). However, results varied during the broiler grow-out phase, 725 mg  $\text{NH}_3$  m<sup>-2</sup> h<sup>-1</sup> at 21 d, 2200 mg  $\text{NH}_3$  m<sup>-2</sup> h<sup>-1</sup> at 35 d, and 2700 mg  $\text{NH}_3$  m<sup>-2</sup> h<sup>-1</sup> at 42 d of grow-out.

No effect was found for the studied factors at 7 d of growth (Table 3) from the model-predicted value. The house (F1) affected ammonia emission at 21 d. At 35 d, there was an interaction ( $p \leq 0.05$ ) between the factors (F1 and F2), meaning that the type of broiler house and the number of flocks were interacting. The average

Table 3 – Analysis of variance for model-predicting ammonia emissions in two different broiler houses (mg m<sup>-2</sup> h<sup>-1</sup>) during two flocks and at four grow out days.

Factor	F (7 d)	F (21 d)	F (35 d)	F (42 d)
Type of aviary (F1)	7.69 ns	12.79*	33.67**	30.03**
Number of flocks (F2)	0.13 ns	0.00 ns	19.06*	4.93 ns
Int. F1 × F2	1.29 ns	0.28 ns	9.98*	0.03 ns
Treatment	3.04 ns	4.36 ns	20.90**	11.66*
Standard deviation	26	193	877	1408
Coefficient of variation (%)	36	22	31	36

\*\*significant at 1 % of confidence ( $p \leq 0.01$ ) F – value; \*significant at 5 % of confidence ( $0.01 \leq p < 0.05$ ) F – value; ns = non-significant ( $p > 0.05$ ).

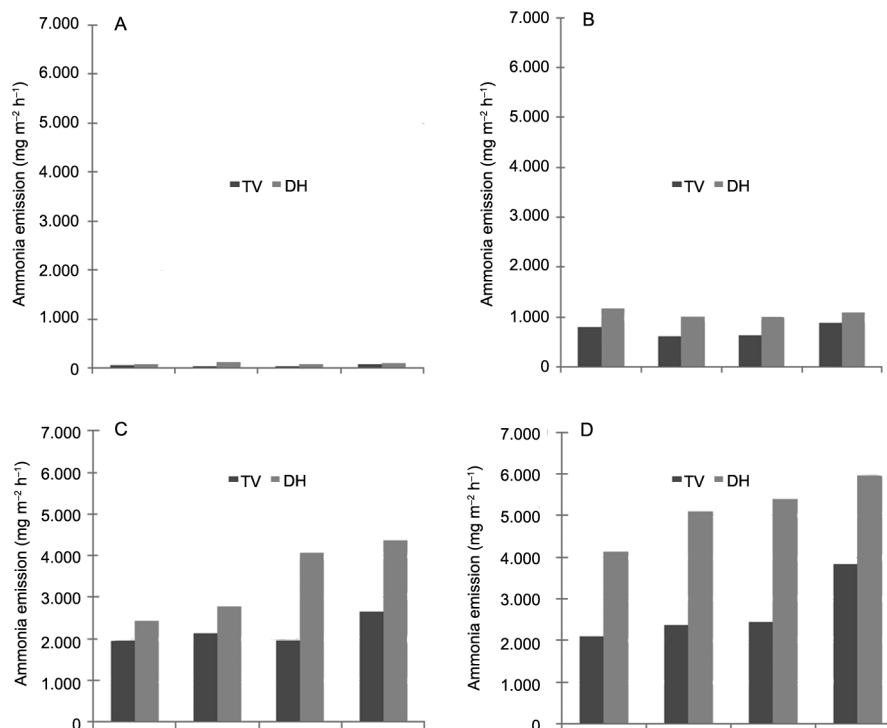


Figure 3 – Model-predicted ammonia emissions from two broiler houses (Tunnel ventilation, TV and dark house, DH) at four grow-out phases, 7 days (A), 21 days (B), 35 days (C) and 42 days (D).

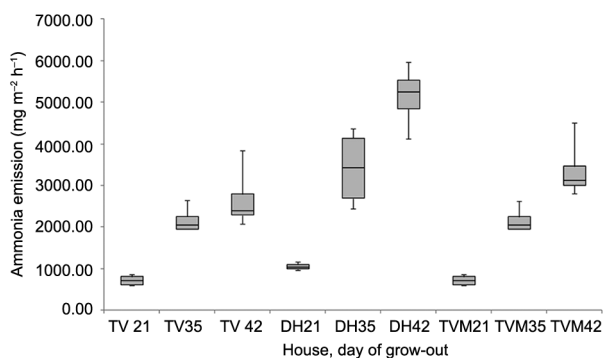


Figure 4 – Box plot of model-predicted ammonia emissions from two broiler houses (tunnel ventilation, TV, dark house, DH) and the measured values using the capsule method (TVM) at 21, 35 days and 42 days of the grow-out phase.

model-predicted value of ammonia emission in DH in the second flock was 5200 mg m<sup>-2</sup> h<sup>-1</sup>, and also on TV with lower emission (2200 mg m<sup>-2</sup> h<sup>-1</sup>; Table 4).

Siefert and Scudlark (2008) studied ammonia emissions from tunnel system houses and found values of 2700 mg NH<sub>3</sub> bird<sup>-1</sup>, equivalent to 2.7 g NH<sub>3</sub> bird<sup>-1</sup>. Results obtained in the present experiment, at 35 d were lower than that with an average emission (in TV and DH) of ~ 4000 mg NH<sub>3</sub> m<sup>-2</sup> h<sup>-1</sup> (12 g NH<sub>3</sub> bird<sup>-1</sup>). Gates et al. (2008) found values of ammonia emission near 20 g NH<sub>3</sub> bird<sup>-1</sup>, practically double the results found in the

present study. Harper et al. (2010) evaluated the weekly average emission during the growth cycle of the birds, which resulted in a total of 4 kg NH<sub>3</sub> per tunnel ventilation house during the summer. The result is similar to that found in the present study, on average 5 kg of NH<sub>3</sub> per flock in tunnel ventilation. Redwine et al. (2002) found that NH<sub>3</sub> emission rates in broiler production varied from 38 to 2105 mg NH<sub>3</sub> h<sup>-1</sup>. Despite the high variations between the results cited, the lowest value in the current literature is similar to that obtained in the present study, when considering the house with a total area of 1800 m<sup>2</sup>. Assuming a market bird weight of 2 kg the highest ammonia emission value found was 12 g NH<sub>3</sub> bird-marketed<sup>-1</sup>.

The highest model-predicted ammonia emission occurred on the 21<sup>st</sup> d of growth in DH (1000 mg NH<sub>3</sub> m<sup>-2</sup> h<sup>-1</sup>). On the 35<sup>th</sup> d, there was an interaction between the "house" and "number of flocks" factors, and the largest model-predicted value of ammonia emission was for DH (4200 mg m<sup>-2</sup> h<sup>-1</sup>) during flock 2, different from flock 1 (2600 mg m<sup>-2</sup> h<sup>-1</sup>). On the last day of growth (market age, 42 d) considering the type of house, the highest model-predicted mean value of ammonia emission in DH (5700 mg m<sup>-2</sup> h<sup>-1</sup>) was found. Model-predicted NH<sub>3</sub> emissions increased along the grow-out cycle, arising from an increase in excreta deposition on litter (Figure 3). The ammonia emission found using the model-predicted ammonia, and those measured inside



Table 4 – Mean model-predicting ammonia emission ( $\text{mg NH}_3 \text{ m}^{-2} \text{ h}^{-1}$ ) in two broiler houses and during two flocks and at four phases of the growth cycle (7, 21, 35 and 42 days).

Factor	Number of flocks				
	1	2	Mean	Standard deviation	Coefficient of variation (%)
	7 d				
TV	40	60	50 a	17	34
DH	100	90	95 a	20	17
Mean	70 a	70 a	-	36	25
Standard deviation	31	18	-	-	-
Coefficient of variation (%)	46	25	-	-	-
	21 d				
TV	700	750	725 b	112	15
DH	1100	1000	1050 a	78	7
Mean	900 a	900 a	-	192	21
Standard deviation	212	173	-	-	-
Coefficient of variation (%)	23	19	-	-	-
	35 d				
TV	2050 aA	2300 bA	2200 b	287	13
DH	2600 aB	4200 aA	3400 a	829	24
Mean	2330 b	3250 a	-	877	31
Standard deviation	317	1005	-	-	-
Coefficient of variation (%)	13	30	-	-	-
	42 d				
TV	2200	3100	2700 b	686	25
DH	4600	5700	5200 a	670	13
Mean	3400 a	4400 a	-	1408	36
Standard deviation	1255	1387	-	-	-
Coefficient of variation (%)	36	31	-	-	-

Tukey test was applied. Mean values followed by the same letter did not differ ( $p > 0.05$ ). For RH, mean values followed by the same letter in the column (lower case) do not differ. Different letters in the same row (upper case) indicate that values differ ( $p \leq 0.05$ ). TV=tunnel ventilation; DH= dark house.

the houses were similar on the grow-out days 21, 35 and 42 in TV. Nevertheless, the values differed from those found in the DH on days 35 and 42 (Figure 4).

The emission rate of ammonia tends to be relatively stable in the first weeks of growth, rising by the third week of life. This increase coincides with the growth period of the birds, and the feed intake is higher than in other phases of the cycle. These emission factors such as concentration of excreta in litter temperature, pH and rate of ventilation may be associated (Harper et al., 2010).

Groot Koerkamp et al. (1998) found values of ammonia emissions in European countries near  $11000 \text{ mg m}^{-2} \text{ h}^{-1}$ . The highest value found in the present study was  $\sim 6000 \text{ mg m}^{-2} \text{ h}^{-1}$  in the DH house (Table 4), which is nearly half of the values found previously. Studying  $\text{NH}_3$  emissions from new and built-up litter Gates et al.

(2008) found that broilers raised on built-up litter emit  $\sim 25 \text{ g NH}_3 \text{ bird-marketed}^{-1}$ . Our highest findings of  $\text{NH}_3$  emissions (with market weight in Brazil near 2 kg) in built-up litter was equivalent to  $12 \text{ g NH}_3 \text{ bird-marketed}^{-1}$ , which is lower than the results for broilers reared in new bedding. Wheeler et al. (2006) found a mean value of  $17 \text{ g NH}_3 \text{ bird-marketed}^{-1}$ , which was similar to the results found in the present study. Values found here were similar to those found by Calvet et al. (2011) in southern Europe ( $24 \text{ g NH}_3 \text{ bird-marketed}^{-1}$ ).

According to Liu et al. (2011) ventilation rate changes inside the housing may be the cause of different results in ammonia emission estimation. Liu et al. (2011) showed that when air velocity increased to a pre-determined level ( $\geq 1.6 \text{ m s}^{-1}$ ), emission flux increases. The loss of nitrogen and water from the litter is no longer negligible, which results in reduced measurements of emission fluxes. The differences in air flow inside the houses might be the reason for significant differences in the ammonia emission results found in current literature (Groot Koerkamp et al., 1998; Wheeler et al., 2006; Gates et al., 2008; Harper et al., 2009; Calvet et al., 2011).

Predicted levels of  $\text{NH}_3$  emissions from the model had a sharp increase after the 35<sup>th</sup> day of grow-out in the DH, when compared to the predictive value of TV, and the measured quantity using the capsule (TVM, Figure 2). The  $\text{NH}_3$  emissions were similar to those estimated in the TV houses but differed substantially from those in the DH house after the 35<sup>th</sup> d of the grow-out cycle.

Whereas the methods applied to this study can be used for estimating ammonia emission trends, the information presented should not be used for making regulatory determinations. However, the model provided comprehensible estimation and might be used as  $\text{NH}_3$  emission abatement strategies. The estimated ammonia emission was higher in the dark house than in the tunnel ventilation system. The amount of ammonia increased gradually throughout the grow-out cycle in both types of houses, and the highest mean value was attributed to the dark house system. The results from the predictive model showed a similar level of ammonia emissions in the tunnel ventilated house, but the level differed from the dark house starting during the broiler grow-out stage.

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