University of São Paulo
"Luiz de Queiroz" College of Agriculture

Gas concentrations and emissions and nutrient flow in broiler houses with litter
reuse

Graciele Angnes

Thesis presented to obtain the degree of Doctor in
Science. Area: Agricultural Systems Engineering

Piracicaba
2017

Graciele Angnes
Environmental Engineer

Gas concentrations and emissions and nutrient flow in broiler houses with litter reuse
versão revisada de acordo com a resolução CoPGr 6018 de 2011

Advisor:
Prof. Dr. **THIAGO LIBORIO ROMANELLI**

Thesis presented to obtain the degree of Doctor in
Science. Area: Agricultural Systems Engineering

Piracicaba
2017

Dados Internacionais de Catalogação na Publicação
DIVISÃO DE BIBLIOTECA – DIBD/ESALQ/USP

Angnes, Graciele

Gas concentrations and emissions and nutrient flow in broiler houses with litter reuse / Graciele Angnes. - - versão revisada de acordo com a resolução CoPGr 6018 de 2011. - - Piracicaba, 2017.

101 p.

Tese (Doutorado) - - USP / Escola Superior de Agricultura "Luiz de Queiroz".

1. Fator de emissão 2. Balanço de massa 3. Qualidade do ar 4. Frangos de corte 5. Relações de concentração I. Título

DEDICATION

I dedicate this thesis to my loving mother and father, Iraci and Astor, my brother Júnior and my sisters Vivian and Giselle whose continuous support and encouragement has allowed me to accomplish my dreams in every aspect of my life. Also, I dedicate this thesis to my loving Maurício whose unconditional love and commitment gives me the strength to follow my ambitions in life.

ACKNOWLEDGEMENTS

My sincerest thanks,

To the University of São Paulo and the 'Luiz de Queiroz' College of Agriculture, for technical, social, and scientific education.

To Capes for providing financial means in my graduation, as well as to Capes, Embrapa, and INRA for the opportunity to participate in Ph.D. exchange.

To Embrapa swine and poultry for providing the equipment and support technically, to the farms for enabling the research, and to my friend Livia for help in field measurements.

To Prof. Thiago Romanelli for guidance and opportunities throughout my academic life.

To Dr. Paul Robin and Mélynda, the directors of this project in France, for providing good ideas in this work and also for a warm welcome in France.

To Dr. Paulo Armando, the director of this project in Embrapa Swine and Poultry, for opportunities throughout my academic life.

To Dr. Arlei Coldebella for help in statistical analysis.

To Biosystems Engineering Department staff, especially Davilmar.

To the library staff of ESALQ/ USP for their help with reviewing and cataloguing.

To all my friends in Piracicaba and colleges from the Biosystems Engineering Department.

To my friends in life, Liana, Deise, Priscila, Ana, Débora, Izabel, Carol, Cleciner, and Suelen.

To my friends in France, especially Alessandra e João, for all their fellowship.

To my family, my parents, brother, and sisters for the incentive.

To my love, who makes me happy every day with her love and kind companionship.

To Michael James Stablein of the University of Illinois Urbana-Champaign for his review of this work.

And in any case, to all those who somehow contributed to the accomplishment of this work.

BIOGRAPHY

Graciele Angnes, daughter of Astor Angnes and Iraci Kirsten Angnes, was born on 06/17/1987 in the city of Concordia, State of Santa Catarina. In 2005, she joined the Environmental Engineering program at the University of Contestado (UNC), which she finished in August 2009. In March 2010, she started the Graduate program (Masters) in Agroecosystems at the Federal University of Santa Catarina - UFSC, SC with a concentration in Socio-environmental Performance in Production Processes, which she finished in May 2012. The dissertation produced the paper: *Correlation of denitrifying catabolic genes with N₂O and N₂ emissions during swine slurry composting*, published in Bioresource Technology, in addition to other papers presented at international conferences. Between 2012 and 2013, she was a teacher and coordinator of the Environmental and Sanitary Engineering course at the University of Contestado. In August 2013, she began her graduate program (doctorate degree) in Agricultural Systems Engineering at School of Agriculture Luiz de Queiroz – Esalq, and in April 2015, she undertook her “sandwich” exchange at the National Institute of Agronomic Research - INRA, France until April 2016.

EPIGRAPH

“Ce qui importe, ce n'est pas d'arriver, mais d'aller vers.”

Antoine de Saint-Exupéry

CONTENTS

RESUMO.....	10
ABSTRACT.....	11
1. INTRODUCTION	13
REFERENCES.....	16
2. NH ₃ AND CO ₂ CONCENTRATIONS AND ENTHALPY INDEX IN BROILER HOUSES WITH REUSED LITTER	21
ABSTRACT.....	21
2.1. INTRODUCTION	21
2.2. MATERIALS AND METHODS.....	23
2.2.1. Broiler houses and management	23
2.2.2. Litter management.....	24
2.2.3. Measurements	24
2.2.3.1. Environmental variables and Thermal comfort index	24
2.2.3.2. NH ₃ and CO ₂ concentrations	25
2.2.3.3. Bird Performance	25
2.2.4. Statistical analysis.....	26
2.3. RESULTS	26
2.3.1. Environmental variables and thermal comfort index.....	26
2.3.2. Broiler performance	30
2.3.3. NH ₃ and CO ₂ concentrations	30
2.4. DISCUSSION.....	32
2.4.1. Environmental variables and thermal comfort index.....	32
2.4.2. NH ₃ and CO ₂ concentrations	34
2.5. CONCLUSIONS	36
REFERENCES.....	37
3. MASS BALANCE IN BROILER HOUSES.....	43
ABSTRACT.....	43
3.1. INTRODUCTION	43
3.2. MATERIALS AND METHODS.....	44
3.2.1. Animals	44
3.2.2. Animal nutrition	44

3.2.3. Litter.....	45
3.2.4. N, C, and P balance.....	45
3.3. RESULTS.....	46
3.3.1. Litter conditions.....	46
3.3.2. Mass balance.....	47
3.4. DISCUSSION	51
3.4.1. Carbon balance	51
3.4.2. Nitrogen balance.....	51
3.5. CONCLUSIONS.....	54
REFERENCES	54
4. EMISSIONS OF AMMONIA AND GREENHOUSE GASES OF BROILER HOUSE IN SOUTHERN BRAZIL.....	57
ABSTRACT.....	57
4.1. INTRODUCTION	57
4.2. MATERIALS AND METHODS	59
4.2.1. Houses.....	59
4.2.2. Animals.....	61
4.2.3. Litter.....	61
4.2.4. Measurements of temperature and air velocity	61
4.2.5. Gas concentrations	62
4.2.6. Gas emission determination.....	62
4.2.6.1. Flux emission	62
4.2.6.2. Method of Concentration ratios	63
4.2.6.3. Validation of the concentration ratio method	64
4.2.7. Batch Emission Rate (ER)	64
4.2.8. Annual Emission Rate (AER)	64
4.2.9. NH ₃ and CO ₂ emissions descriptors.....	64
4.2.10. Statistics	65
4.3. RESULTS.....	65
4.3.1. Litter properties	65
4.3.2. NH ₃ and CO ₂ flux emission	65
4.3.3. Gas emissions rate	66
4.3.4. Annual emission rate.....	69

4.3.5. Emissions descriptors.....	69
4.4. DISCUSSION.....	70
4.4.1. Emissions rates.....	70
4.4.1.1. Gas emission rate.....	70
4.4.1.2. Annual emission rate.....	71
4.4.2. Emissions fluxes descriptors.....	72
4.5. CONCLUSION.....	75
REFERENCES.....	75
5. GENERAL CONCLUSIONS AND FINAL REMARKS	81
APPENDIX.....	83

RESUMO

Concentrações e emissões de gases e fluxo de nutrientes em aviários de frangos de corte com cama reutilizada

A produção comercial de frangos de corte emite baixas quantidades de óxido nitroso e metano, no entanto, a produção de dióxido de carbono e amônia é considerável. Vários países têm buscado investigar as emissões de gases do efeito estufa (GEE) e amônia (NH_3) na produção de frangos de corte já que as informações disponíveis na literatura são variáveis e incertas devido à diversidade das instalações, bem como das inúmeras diferenças no sistema de criação e das complexas interações observadas nos dejetos dos animais. Atualmente, a determinação das emissões gasosas exigem técnicas com custo elevado e difíceis de colocar em prática em um número elevado de instalações. Além disso, os impactos dos sistemas produtivos sobre o aquecimento climático devem ser medidos para permitir que o Brasil atenda os compromissos firmados na COP-21 e execute seu inventário de maneira mais precisa. A fim de obter resultados confiáveis é necessário conhecer os fatores de emissão na diversidade de sistemas de produção existentes no país. Diante dessa complexidade, nesta pesquisa buscou-se aplicar uma técnica simplificada de amostragem e determinação das emissões que apresenta baixo custo, simplicidade e robustez. A metodologia utiliza como referência, o princípio das relações de concentração e a concentração dos gases, que nesse caso foi determinada pelo INNOVA 1412. Buscou-se monitorar semanalmente as concentrações de NH_3 , CO_2 , CH_4 e N_2O considerando o manejo de reutilização da cama de frango. A qualidade do ar foi avaliada, considerando as concentrações de NH_3 e CO_2 recomendadas por instituições internacionais, assim como o conforto térmico dos aviários considerando os índices de entalpia propostos na literatura e o desempenho zootécnico. Determinou-se os fatores de emissão. E para identificar as variáveis que melhor descrevem o fluxo de emissão de NH_3 e CO_2 , foram testados modelos lineares mistos com até seis variáveis. Balanços de N, C e P foram conduzidos para cada ciclo de produção com a finalidade de contabilizar as entradas e saídas dos elementos e verificar a precisão das metodologias utilizadas. A principal entrada de N e C no sistema foi pela reutilização da cama, seguida pela ração. As emissões permitiram calcular perdas anuais de 16 ± 4 ; 61 ± 16 ; e 168 ± 43 g de N_2O , CH_4 e NH_3 ave-alojada⁻¹ ano⁻¹, respectivamente. Considerando que esta pesquisa apresenta uma metodologia aplicável e de baixo custo para determinar as emissões de GEE em aviários de frangos de corte no Brasil, os resultados são úteis para incentivar novas pesquisas que possam avançar no conhecimento das emissões e possíveis técnicas de mitigação de GEE na produção de frangos de corte no Brasil.

Palavras-chave: Fator de emissão; Qualidade do ar; Balanço de massa; Relações de concentração

ABSTRACT

Gas concentrations and emissions and nutrient flow in broiler houses with litter reuse

The commercial production of broiler chickens emits low amounts of nitrous oxide and methane, however, the production of CO₂ and NH₃ is considerable. Several countries have sought to investigate the emissions of greenhouse gases (GHG) and ammonia (NH₃) in the production of broiler chickens since the information available in the literature is variable and uncertain. This is due to the diversity and particular conditions of the facilities, as well as the innumerable differences in the production system and the complex interactions observed in animal waste. Currently, gaseous pollutant measurements are costly techniques and difficult to put into practice in a large number of operations. The impacts of agriculture on global warming must be measured to allow Brazil to meet the commitments signed in COP-21 and to manage its production more precisely. In order to obtain reliable results, it is necessary to know the emission factors for the diverse production systems in the country. In view of this complexity, this research sought to apply a simplified sampling and emission determination technique that present low cost, simplicity, and robustness. The methodology uses the principle of concentration relations as a reference and determination of the concentration of gases was performed by INNOVA 1412. Weekly monitoring of concentrations of NH₃, CO₂, CH₄, and N₂O was conducted, considering the typical management of reused litter. The air quality was evaluated for the concentrations of NH₃ and CO₂, as recommended by international institutions. In addition, the thermal comfort of broiler house, considering the enthalpy index proposed in the literature and zootechnical performance, were measured. In order to identify the variables that best describe the emission flux of NH₃ and CO₂, mixed linear models with up to six variables were tested. N, C, and P balances were conducted for each production cycle in order to account for the inputs and outputs of the elements, as well as to verify the accuracy of the methodologies used. The main input of N, C, and P in the system was from reused litter, followed by the feed. The emissions allowed for the calculation of annual losses of 16 ± 4 ; 61 ± 16 , and 168 ± 43 g of N₂O, CH₄, and NH₃ bird-place⁻¹ yr⁻¹, respectively. Considering that this research presents an applicable and innovative methodology to determine GHG flows in broiler house for the country, the data will be useful for the Brazilian annual production of GHG emissions from poultry. The results are also useful to encourage new research that promotes knowledge of GHG emissions and alternatives to decrease emissions for meat production in Brazil.

Keywords: Emissions rates; Air quality; Mass balance; Concentration relations

1. INTRODUCTION

According to the FAO (2016), the major challenges facing mankind today are issues related to food production for the population, such as ensuring food security in the face of climate change and reducing greenhouse gas emissions.

Currently, GHG emissions (carbon dioxide - CO₂, methane - CH₄ and nitrous oxide - N₂O) and climate change are issues that are widely debated by the global scientific community. The Intergovernmental Panel on Climate Change (IPCC) emphasized in its "5th Assessment Report" that GHG emissions from anthropogenic actions are the main causes of current climate change (IPCC, 2014). More recently, the pact signed at COP-21 in 2015 that was ratified in 2016 by 35 countries, including Brazil, will require concrete and urgent measures to adapt to global climate change, such as reducing the emission of gaseous pollutants and the rate of global warming. To achieve these objectives, the quantification and monitoring of emissions are urgently needed to understand the dynamics of gas formation and the variables that affect the process in the production systems.

Agricultural production accounts for approximately 37% of GHG emissions in Brazil with livestock accounting for 14.5%, according to data from the Ministry of Science, Technology, Innovation, and Communications (MCTI, 2014). For the Brazilian Agricultural Research Corporation (EMBRAPA, 2015), tactics to increase the efficiency of production systems and improve animal performance can reduce these emissions by up to 35%.

In this scenario, the challenge of Brazilian agriculture is to evaluate and monitor the pollutant gases in production systems, as well as to suggest strategies for good practices and the adoption of policies aimed at mitigating emissions. This is an attempt to contain the environmental impacts and make Brazilian agriculture more sustainable and competitive in the international market. The evolution of Brazilian livestock in the last decades has brought about an intensification of production systems, and this intensification through animal confinement increases the environmental impact (PETERSEN, 2008). During facility operation, accumulation of animal wastes, which undergo a series of reactions, such as decomposition, hydrolysis, ammonia volatilization (NH₃), nitrification, denitrification, and fermentation, favor the emission of gases into the environment.

In addition, confinement associated with some management practices may increase the potential for high gas concentrations, lower O₂ concentrations, and promote inadequate thermal environment that compromises animal welfare (FAIRCHILD, 2009; HAI et al., 2000). On the other hand, the development of these systems allows for greater control of the production efficiency, mainly in the production of broilers.

Poultry is one of the agricultural activities with greater development in recent decades. This development was supported by constant improvement in the performance of the strains, the genetic selection, as well as the improvement in supply conditions, management, facilities, sanitation, etc.

The current major challenges in the production of broiler chickens are the availability of natural resources, the persistence of trade barriers, price of raw materials, reduction of greenhouse gases emissions (GHG), and the consumer demands, which are increasingly concerned with issues related to animal welfare, food safety, and environmental impact of the activity (IPCC, 2014; FAO, 2013).

The importance of air quality for animal feeding operations has been well recognized, especially in Brazil, which is among the largest animal producers. Emission estimates are needed to assess the broiler industry's impact on local and regional air quality for identification of possible reduction techniques.

One of the major environmental concerns in the poultry industry is NH_3 volatilization (MOORE, 1998), but in these production systems, GHG can also be emitted. Ammonia and its chemical combinations are important components responsible for acidification (GROOT KOERKAMP et al., 1994). Ammonia emissions from poultry litter originate from microbial degradation of compounds such as uric acid, feed efficiency, and, to a lesser extent, urea are potential sources for the production of NH_3 gas (WOOD, 2015).

Due to its digestive physiology, poultry is monogastric and produces only slight amounts of CH_4 (PEDERSEN et al., 2008). However, methane can be emitted from litter reactions inside the building, manure storage, and fermentation of organic matter during manure application (CALVET et al., 2011a). N_2O production of poultry manure depends on composition of the excreta, enzymes involved, in addition to the conditions after excretion (XIN et al., 2011). The main source of carbon dioxide is animal respiration and decomposition of organic matter (KNÍŽATOVÁ et al. 2010).

In Brazilian inventories, the GHG estimates for the agricultural sector are restricted to methane (CH_4) and nitrous oxide (N_2O), while CO_2 emissions are excluded. This is due to the theoretical zero balance, which considers that the CO_2 emitted into the atmosphere returns through photosynthesis of plants, resulting in the production of grain, for example.

Production and emission of gases in poultry facilities involve complex processes, and a high number of variables may influence the rate of emissions (CALVET et al., 2011a; XIN et al., 2011; BROUČEK & ČERMAK, 2015).

Knowledge of scientific estimates of GHG and NH_3 emissions in the Brazilian broiler production systems is still limited. Some emissions data were presented by Hernandez et al. (2001), Miragliotta et al. (2004), Menegali et al. (2009), and Carvalho et al. (2011). These studies are important for the development of ventilation and exhaust systems to improve animal welfare but do not provide the emission factors and accurate estimates of emissions by category of animal, which is an important consideration for GHG inventories.

Prudêncio da Silva et al. (2014) conducted a life cycle analysis (LCA) to assess the poultry production system in two regions of Brazil and France. In the absence of emission factors of poultry litter in Brazilian conditions, they used French data as an alternative.

More recently Henn et al. (2015) presented models to estimate CO_2 emissions produced by two strains of broiler chickens, and Lima et al. (2015) developed a model to estimate emissions of ammonia considering variables such as acidity, litter temperature, and age of the animals. However, the method utilized allows for sampling the amount of ammonia emissions in a particular area of the litter, hindering the representation of heterogeneity of litter conditions that may exist in a commercial broiler house. Usually, these areas are located near the feeders and drinkers and may have different moisture contents, as well as differing pH and temperature (CARR et al. 1990; MILES, 2006).

However, efforts to mitigate these emissions are confounded by a lack of information, understanding of the processes of emissions is necessary to improve accuracy of quantification and simplicity in estimating emissions. This one of the technical challenges to quantify emission in Brazil.

Hassouna and Eglin (2015) listed the main measurement methods applied in livestock farming: passive diffusion samplers, denuder tubes, trapping in an acid solution, continuous sampling, air samples using sample bags, colorimetric gas detector tubes, gas chromatography, chemiluminescence, fourier transform and photoacoustic infrared absorption spectroscopy, differential optical absorption spectroscopy, laser absorption spectroscopy, mass balance, concentration ratios and mass balance, static flux chambers, dynamic flux chambers, and wind tunnels.

In broiler houses, the methodologies most utilized to sample emissions are: static flux chambers, dynamic flux chambers, and wind tunnels applied in litter, and the gas concentrations are measured by gas chromatography, acid solution to trap ammonia (GUIZIOU BELINE, 2005; MILES et al., 2006; 2011; LIMA et al., 2015), and by photoacoustic infrared analyzer (LIN et al., 2012; MILES et al., 2014; CALVET et al., 2014).

The continuous air samples are recommended by Jungbluth (2001) because they can reflect changes in ventilation rates but also differences of gas concentrations related to the activity of animals (diurnal effect), in addition to the effects of seasons. These measurements are possible in experimental conditions but are more difficult to implement on a large number of commercial farms, due to the high investment costs and daily maintenance of measuring devices.

To meet the expectations set by the Kyoto Protocol and emission factors proposed by the IPCC with the small number of measurements of gas concentrations, the French Livestock Institute has developed, put up, and validated a simplified methodology for determining emissions in broilers houses (EHLACHER, 2008).

Apart from the diversity of gas sampling methodologies and method for determination of gas concentration, the large differences in system productions around the world are not representative of the emissions factors.

In Brazil, particularly, given the expansion and variability of the Brazilian territorial area, there are differences in broiler houses, production management, batch density, litter management, building dimensions, and ventilation systems. Therefore, emissions inventories in Brazil have largely relied on emission rates that are not representative for all regions of Brazil.

In recent years, the "Dark house"-type broiler houses have become almost ubiquitous in some regions of Brazil (BICHARA, 2009). This system was initially developed to control the photoperiod and more recently has been focused on thermal insulation and control of environmental variables to provide more efficient performance in comparison with conventional broiler houses (ROVARIS et al., 2014).

This system has been used for a long time in other countries for broilers. According to Abreu and Abreu (2011), the system has an automatic feeder and nipple drinker. Cooling systems can be nebulized or have pad cooling. It has a black polyethylene liner on one side and black or clear on the other side. Some producers use baffles on the ceiling. The litter is usually reused by up to six batches with the absence of health problems. However, Avila et al. (2007) reported that some companies work with 12 reuse cycles. Currently, the reuse of the litter between two and three years has been common practice in broiler houses located in the south of the country. This is an interesting alternative for farmers because it reduces the price of production and amount of waste generated.

However, there are reports where the ammonia concentrations may exceed the limits recommended by some authors for animal welfare when minimum ventilation conditions are maintained (CARVALHO et al., 2011). In addition, the reuse of litter can be responsible for an increase in the ammonia emissions and cause health problems in the batches (SILVA, 2007).

Differences in the broiler houses may affect the environmental conditions, moisture, ammonia content, and heterogeneity of litter, changing the GHGs emissions rate (LIMA et al., 2015). Litter conditions are also suggested to be correlated with emissions by Groot Koerkamp et al. (1998) and Wheeler et al. (2006).

Moreover, litter type, litter management, humidity, and temperature (CALVET et al., 2011b; REDDING, 2013), season of the year (MIHINA et al., 2010; CASEY et al., 2004), ventilation rate, (KNÍŽATOVÁ et al., 2010b; WALKER et al., 2014) ventilation system, bird's diet, and age (GATES et al., 2008; PESCATORE et al., 2005; HARPER et al., 2010; LIN et al., 2012) already have been reported in the literature as variables affecting emissions.

Management of the production batches adopted by the farmer can be an important factor in emissions of gases because it falls on the quality of the litter and environmental conditions for the animals.

While many of these factors are already known, there is still a lack of information on some important factors, making the interpretation and comparison of published data complicated.

This study was part of the project developed by the Brazilian Agricultural Research Company - Embrapa, denominated as "Greenhouse gases (GHG) dynamics in Brazilian livestock production systems - Pecu network".

The primary objective of the current study was to determine emissions factors of NH_3 , and GHG (CH_4 , CO_2 and N_2O) from three commercial broiler houses (dark house) in southern Brazil for reused litter and to identify which are the variables that are most important to describe the emissions. Finally, a comparison was performed between the concentration ratio and mass balance to evaluate the reliability of the simplified methodology.

To meet the objectives set out in this thesis, three chapters were written, in addition this first chapter of introduction, which include some economic and environmental aspects for the production of broilers with such production conditions and practices in dark houses described herein.

In Chapter 2, the objective is to present and compare the NH_3 and CO_2 concentration levels, enthalpy index observed, and animal performance.

In Chapter 3, the physical balance of the production process is presented with consideration for the mass balance. In Chapter 4, the objective was to measure and to determine the direct emission factors of CO_2 , NH_3 , and GHG (CH_4 , N_2O) over four consecutive batches. In addition, another objective was to identify possible influences of variables such as weight of the animals, the litter reuse, and physical and chemical attributes of the litter in ammonia and carbon dioxide emissions.

References

- ABREU, V. M. N.; ABREU, P. G. Os desafios da ambiência sobre os sistemas de aves no Brasil. **Revista Brasileira de Zootecnia**, viçosa, v. 40, n. 2, p. 1-14, 2011.
- AVILA, V. S. de; COSTA, C. A. F.; FIGUEIREDO, E. ROSA, P. S., ABREU, V.M.N. Materiais alternativos em substituição à maravalha como cama de frangos. **COMUNICADO TÉCNICO 465**, EMBRAPA CNPSA, Concórdia, 5p., 2007.
- BICHARA, T. Aviário azul e dark-house para frangos de corte -Desenvolvendo novos conceitos para aviários pressão negativa. In: X SIMPÓSIO BRASIL SUL DE AVICULTURA E I BRASIL SUL POULTRY FAIR. **Proceedings...** Chapecó, 2009.
- BROUČEK, J. ČERMÁK, B. EMISSION OF HARMFUL GASES FROM POULTRY FARMS AND POSSIBILITIES OF THEIR REDUCTION. **Ekologia**. Russia, v.34, Issue 1, P. 89–100, March, 2015.
- CALVET, S.; CAMBRA-LÓPEZ, M.; ESTELLÉS, F.; TORRES, A. G. Characterization of gas emissions from a Mediterranean broiler farm. **Poultry Science**, Oxford, v.90, p.534-542, 2011a.
- CALVET, S.; ESTELLÉS, F.; CAMBRA-LÓPEZ, M.; TORRES, A. G.; VAN DEN WEGHE, H. F. A. The influence of broiler activity, growth rate, and litter on carbon dioxide balances for the determination of ventilation flow rates in broiler production. **Poultry Science**, Oxford, v.90, p.2449- 2458, 2011b.
- CALVET, S.; GATES, R. S.; ZHANG, G.; ESTELLE'S, F.; OGINK, N.; PEDERSEN, S.; BERCKMANS, D. Measuring gas emissions from livestock buildings: a review on uncertainty analysis and error sources. **Biosystems Engineering**, Amsterdam, v. 116, p. 221-231, 2014.

- CARR, L. E.; WHEATON, F. W.; DOUGLASS, L. W. Empirical models to determine ammonia concentrations from broiler chicken litter. **Transactions of the ASAE**, St. Joseph, v.33, p.1337–1342, 1990.
- CARVALHO, T. M. R.; MOURA, D. J.; SOUZA, M. Z.; SOUZA, G. S.; BUENO, L. G. F. Qualidade da cama e do ar em diferentes condições de alojamento de frangos de corte. **Pesquisa Agropecuária Brasileira**, Brasília, v.46, n.4, p. 351-361, 2011.
- CASEY, K.D., GATES, R.S., Wheeler, E.F. Xin, H., Zajackowski, J.L., Topper, P.A., Liang, Y. Ammonia emissions from Kentucky broiler houses during winter, spring, and summer. In: PROCEEDINGS OF THE 97TH ANNUAL A&WMA CONFERENCE AND EXHIBITION: SUSTAINABLE DEVELOPMENT. **Proceedings...**, Pittsburgh, p 629, 2004.
- EHRLACHER, ARNAUD. Application et validation d'une methodologie simplifiee de mesure des emissions gazeuses en batiments avicoles. **Master**. Universite de Haute-Alsace, UHA, Alsace. 130p. 2008.
- FAIRCHILD, B. D. Environmental factors to control when brooding chicks. **Technical Bulletin n.1287**, Cooperative Extension Service, University of Georgia, Georgia. 2009.
- FAO. **The state of food and agriculture: food systems for better nutrition**. Rome, 2013.
- GATES, R. S.; CASEY, K. D.; WHEELER, E. F.; XIN, H.; PESCATORE, A. J. U. S. Broiler housing ammonia emissions inventory. **Atmospheric Environment**, Oxford, v. 42, p. 3342-3350, 2008.
- GROOT KOERKAMP, P. W. G. Review on emissions of ammonia from housing systems for laying hens in relation to sources, processes, building design and manure handling. **Journal of Agricultural Engineering Research**, Amsterdam, v. 59, p. 73-87, 1994.
- GUIZIOU, F.; BÉLINE, F. In situ measurement of ammonia and greenhouse gas emissions from broiler house in France. **Bioresource Technology**, Amsterdam, v. 96, p. 203-207, 2005.
- HAI, L.; RONG, D.; ZHANG, Z.Y. The effect of thermal environment on the digestion of broilers. *Anim Physiol*. San Francisco, v.83(2), p.57–64, 2000.
- HARPER L.A; FLESCHE T.K; WILSON J.D. Ammonia emissions from broiler production in the San Joaquin Valley. **Poultry Science**, Oxford, v. 89, p.1802-814, 2010.
- HASSOUNA, M.; EGLIN T. **Mesurer les émissions gazeuses en élevage : gaz à effet de serre, ammoniac et oxydes d'azote**. Diffusion INRA-ADEME, France, 314p. ISBN : 2-7380-1375-9, 2015.
- HENN, J. D.; BOCKOR, L.; BORILLE,R.; COLDEBELLA, A.; RIBEIRO, A. M. L.; KESSLER, A. de M. Determination of the equation parameters of carbon flow curves and estimated carbon flow and CO2 emissions from broiler production. **Poultry Science**, Oxford. v.94, p. 2303-2312, 2015.
- HERNANDES, R.; CAZETTA, J.O. Método simples e acessível para determinar amônia liberada pela cama aviária. **Revista Brasileira de Zootecnia**, Viçosa, v.30, p.824-829, 2001.
- IPCC. Mitigation of climate change: contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: **Cambridge University Press**, 2014.
- JUNGBLUTH T, HARTUNG E, BROSE G. Greenhouse gas emissions from animal house and manure stores. **Nutr Cycle Agroecosyst.**, Amsterdam, v.60,p.133–45, 2001.
- KNÍŽATOVÁ, M., MIHINA, Š., BROUČEK, J., KARANDUŠOVSKÁ, I. & MAČUHOVÁ J. The influence of litter age, litter temperature and ventilation rate on ammonia emissions from a broiler rearing facility. **Czech Journal of Animal Science**, Czech, v.55, p.337–345. 2010.
- LIMA, N. D. S.; GARCIA, R. G.; NÄÄS, I. A.; CALDARA, F. R.; PONSO, R. Modelpredicted ammonia emission from two broiler houses with different rearing systems. **Scientia Agricola**, Piracicaba, v. 72, p. 393-399, 2015.

- LIN, X. J.; CORTUS, E. L.; ZHANG, R.; JIANG, S.; HEBER, A. J. Air emissions from broiler houses in California. **Transactions of the ASABE**, St. Joseph, v. 55, p. 1895-1908, 2012.
- MEDA, B.; HASSOUNA, M.; AUBERT, C.; ROBIN, P.; DOURMAD, J. Y. Influence of rearing conditions and manure management practices on ammonia and greenhouse gas emissions from poultry houses. **World's Poultry Science Association**, Cambridge, v. 67, p. 441-456, 2011.
- MENEGALI, I.; TINÓCO, I.F.F.; BAÊTA, F.C.; CECON, P.R.; GUIMARÃES, M.C.C.; 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**, Campina Grande, v.13, p.984-990, 2009.
- MCTI, MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO. Segundo Inventário Brasileiro de Emissões e Remoções Antrópicas de Gases de Efeito Estufa - Relatórios de Referência do Setor Agricultura. **MCTI**, Brasília, 2014.
- MIHINA, Š., KNÍŽATOVÁ, M. & BROUČEK J. Effect of season on carbon dioxide and ammonia production in broiler housing. In Selected problems of soil tillage systems and operations. Faculty of Production Engineering, **Warsaw University of life Sciences**. Warsan, p. 123–133. 2010.
- MILES, D. M.; BROOKS, J. P.; SISTANI, K. Spatial contrasts of seasonal and intraflok broiler litter trace gas emissions, physical and chemical properties. **Journal of Environmental Quality**, Madison, v. 40, p. 176-87, 2011.
- MILES, D. M.; OWENS, P. R.; ROWE, D. E. Spatial variability of litter gaseous flux within a commercial broiler house: ammonia, nitrous oxide, carbon dioxide, and methane. **Poultry Science**, Oxford, v. 85, p. 167-172, 2006.
- MILES, D.M.; MOORE, P.A.; BURNS, R.T.; BROOKS, J.P. Ammonia and Nitrous Oxide Emissions from a Commercial Broiler House. **Journal Environmental Quality**. Madison, USA. V.43, p.1119–1124, 2014.
- MIRAGLIOTTA, M. Y.; NÄÄS, I. A.; MURAYAMA, M. C.; MOURA, D. J. Software para estimativa de emissão de amônia em alojamento de frangos de corte. **Revista Brasileira de Agroinformática**, São Paulo, v. 6, p. 79-89, 2004.
- MOORE, P. A., JR. Best management practices for poultry manure utilization that enhance agricultural productivity and reduce pollution. In J. Hatfield and B.A. Stewart (ed.) Animal waste utilization: Effective use of manure as a soil resource. **Ann Arbor Press**, Chelsea, p. 89-117, 1998.
- PEDERSEN S, BLANES-VIDAL V., JOERGENSEN H., CHWALIBOG A., HAEUSSERMANN A., HEETKAMP M.J.W., AARNINK A.J.A. Carbon dioxide production in animal houses: a literature review. In AGRICULTURAL ENGINEERING INTERNATIONAL, CIGR Ejournal. **Proceedings...** St. Joseph, 2008.
- PESCATORE, A. J.; CASEY, K. D.; GATES, R. S. Ammonia emissions from broiler houses. **Journal of Applied Poultry Research**, Athens, GA, v. 14, p. 635-637, 2005.
- PRUDÊNCIO DA SILVA, V. P.; WERF, V.D; SOARES, H.M.G; CORSON, M. S. Environmental impacts of French and Brazilian broiler chicken production scenarios: an LCA approach. **Journal of Environmental Management**, Amsterdam, v. 133, p. 222-231, 2014.
- REDDING, M.R. Bentonite can decrease ammonia volatilisation losses from poultry litter: laboratory studies. **Animal Production Science**, Oxford, v.53, p. 1115–1118, 2013.
- ROVARIS, E.; CORRÊA, G. S. S.; CORRÊA, B. A.; LUNA, U. V. Avaliação da conversão alimentar e do ganho médio de peso diário de frangos de corte em dois sistemas de produção – dark house e convencional. In XXII CONGRESSO BRASILEIRO DE ZOOTECNIA. **Proceedings...**Cuiabá, 2012.

- SILVA, M.A.N.; BARBOSA FILHO, J.A.D.; SILVA, C.J.M.; ROSÁRIO, M.F.; SILVA, I.J.O.; COELHO, A.A.D.; SAVINO, V.J.M. Avaliação do estresse térmico em condição simulada de transporte de frangos de corte. **Revista Brasileira de Zootecnia**, Viçosa-MG, v.36, n.4, p.1.126- 1.130, 2007.
- WALKER, J.T.; ROBARGE, W.P.; AUSTIN R.. Modeling of ammonia dry deposition to a pocosin landscape down-wind of a large poultry facility. Agriculture, **Ecosystems and Environment**, Amsterdam, V. 185, p.161–175, 2014.
- WHEELER, E.; CASEY, K.; GATES, R. S.; XIN, H.; ZAJACZKOWSKI, J. L.; TOPPER, P. A.; LIANG, Y.; PESCATORE, A. J. Ammonia emissions from twelve U.S.A. broiler chicken houses. **Transactions of the ASAE**, St. Joseph, v. 49, p. 1495-1502, 2006.
- WOOD, D.; COWHERD, S.; VAN HEYSt, B. A summary of ammonia emission factors and quality criteria for commercial poultry production in North America. **Atmospheric Environment**, Oxford, v. 115, p. 236-245, 2015.

2. NH₃ AND CO₂ CONCENTRATIONS AND ENTHALPY INDEX IN BROILER HOUSES WITH REUSED LITTER

ABSTRACT

Additionally to high ambient temperature in broiler houses, high concentrations of atmospheric ammonia (NH₃) and carbon dioxide (CO₂) can negatively affect production and health of animals. Thermal discomfort can cause reduced feed consumption, digestive inefficiency, impaired metabolism, and even death. Ammonia is the dominant pollutant gas in poultry houses and, as well as carbon dioxide, is one of the key environmental stressors affecting broiler production performance. This paper focused on the measurement of concentrations of ammonia and carbon dioxide and applied the enthalpy index to evaluate the air quality and thermal comfort in three mechanically-ventilated dark house type broiler houses. For evaluating thermal comfort, the comfort enthalpy index recommended by literature, was used. Average age was 41 days and bedding consisted with reused litter over two years. Average NH₃ and CO₂ concentrations were 8.38 ± 6 and 931 ± 348 ppm, respectively. The minimum and maximum outdoor temperature values were respectively 17.5 °C and 38.4 °C and mean 26.5 ± 4 °C, the average indoor temperature was 27 ± 3 °C. The enthalpy was closer to the comfort bands during the 1st, 2nd and 3rd weeks. The enthalpy index was more adequate from 1st to 4th weeks. The percentage of comfort calculated based on the indexes varied between 50 and 60% among the three dark houses. Although the values of enthalpy are above the recommended comfort ranges in the last weeks no was unsatisfactory index of productivity. Even with extended litter reuse, NH₃ and CO₂ concentrations agree well with other studies that utilized new litter or reused litter by fewer batches.

Keywords: Ammonia; Carbon dioxide; Air quality; Thermal comfort

2.1. Introduction

Commercial poultry production systems consist of several sub-sectors, including breeding, commercial egg production, and meat production. Regarding this last item, the Brazilian southern states stand out in the production of chickens, holding 63% of the national slaughter (ABPA, 2016). Thus, it is estimated that the Brazilian poultry industry continues to grow quickly, needing to bear the responsibility for the production sustainability issues and focus on social aspects, environmental preservation, and animal welfare. The new market demands for environmental issues, food safety, and animal welfare are invariably related to the thermal environment and air quality of the premises (KOELKEBECK, 2013).

An ideal poultry facility should provide optimal environmental conditions, involving gaseous concentrations required for the animals, particulate matter, temperature, relative humidity and microorganisms, and thereby, improve the quantity and quality of production (KOELKEBECK, 2013; POLAT, 2015).

Thereby, modern poultry housing was designed to reduce heat loss and improve energy efficiency. However, in some management situations, inadequate air exchange can result in a concentration increase of CO₂, NH₃, moisture, dust, and odors, decreasing the concentrations of oxygen (O₂) and the indoor air quality, in addition to resulting in inadequate thermal ambience (OLANREWAJU et al., 2008; FAIRCHILD, 2009).

To evaluate the thermal comfort of the installations, thermal comfort indexes can be used. The comfort indexes quantify and qualify the thermal discomfort of the animals. Among these indices, enthalpy has been

proposed as the most suitable index for the environmental evaluation of broiler operations (NAZARENO et al., 2009; NAZARENO et al., 2011; SILVA et al., 2007; PEREIRA, 2007). Enthalpy expresses the amount of energy contained in the dry air and is calculated by temperature, humidity, and atmospheric pressure. According to Savastano Junior et al., (1997), the greater the enthalpy of air, the greater the heat in the environment.

Climate change and the expansion of poultry production increased the concern for the poultry industry for heat-related stress (WINDHORST, 2006). The negative balance between the amount of heat energy produced by a chicken and the net energy released into the environment is determined by Coble et al., (2014) as heat-stress. This can cause feed conversion deteriorates (MIRAGLIOTTA et al., 2006), digestion inefficiency, impaired metabolism (HAI et al., 2000; Coble et al., 2014), high prostration and high mortality rates (MOURA, 2001). Relative humidity is also important and affects the thermal comfort of birds when the ambient temperature reaches 25°C. High relative humidity rates, associated with high concentrations of ammonia can affect the immune response of birds (WEI et al., 2015).

High concentrations of gaseous ammonia also can have adverse effects on production performance (MILES et al., 2004). The greatest problem caused by atmospheric ammonia is reduced growth performance, which results in lower body weight gain and higher feed conversion ratios (YI et al., 2016). Other studies evaluating the air quality in the production of broiler chickens found a strong relationship between the concentrations of gases, such as NH_3 and CO_2 , and the development of respiratory diseases in broilers (REECE et al., 1980; ALENCAR et al., 2004; RONCHI, 2004; RITZ et al., 2006; OWADA et al., 2007; MELUZZI and SIRRI, 2009).

Carbon dioxide levels above 1.2% caused negative effects on chicks and broilers such as, reduction of feed intake and reduction of growth (MENEGALI, 2005).

Ammonia concentrations in the air above 60 ppm give the most exposed or predisposed birds respiratory disease, increase the risk of secondary infections by vaccines, and impair the physiological processes of gas exchange (Oliveira et al., 2003). This gas can cause stress in the chickens, which leads to weight loss and can lead to death of the chickens (HERNANDES and CAZETTA, 2001). Meng et al., (2016) reported that when ammonia concentration rise (≥ 50 ppm), the broilers have higher probability and degree of dirty feathers, elbow and foot pad infection, lameness, and unsteady gait. Miles et al., (2006) found that birds exposed to 25 ppm (lower concentration) of ammonia gas developed ocular abnormalities but at a slower rate when compared with birds exposed to 50 and 75 ppm (higher concentrations). This same author also observed that birds exposed to high levels final body weight was depressed by 6 and 9% (MILES et al., 2004) Wei et al., (2014) and Piórkowska et al., (2015) also observed that high concentrations of ammonia (70 ppm) can reduce growth performance and meat quality of broilers. Previous laboratory studies also have shown that high concentrations of environmental ammonia can alter body fat distribution and lipid metabolism (YI et al., 2016).

Some welfare and organic production organizations recommend a concentration limit for exposure to ammonia. The Standards Comparison Organization (2013) emphasizes that the NH_3 concentration should be below 10 ppm and not exceed 25 ppm. According to Meng et al., (2016), the ammonia concentrations in the house have to be controlled within 25 ppm to ensure the broilers health and animal welfare. However, the studies conducted so far show great variation in concentration in broiler houses, ranging from 1 to 50 ppm (REDWINE et al., 2002). For CO_2 concentrations, the recommended range is around 3000 ppm and should not exceed 5000 ppm.

Studies have revealed that several variables can affect the production and release of NH_3 and CO_2 gaseous compounds (KNOWLTON, 2000; SEEDORF & HARTUNG, 2002; WHEELER et al., 2003; RICHARD et al., 2005; MOSQUERA et al., 2005; COUFAL, 2006). And between these variables, Redwine et al., (2003) observed

that the type of litter management has the potential to release large quantities of NH_3 due to the accumulation of available nitrogen to support microbes in the litter, in addition, a study of Wheller et al., (2003) on reused litter (4 to 5 batches) showed that NH_3 concentration could not be maintained below 25 ppm during minimum ventilation.

There are also some studies on the spatial variability of gas concentration and the litter conditions inside broiler houses (TASISTRO et al., 2004; MILES et al., 2006; 2008).

In Brazil, some studies were carried out for the ammonia concentrations to be checked, evaluating the influence of the ventilation system and the quality of the litter (LIMA et al., 2011; FURTADO et al., 2010; MENEGALI et al., 2009). There is lack of data corresponding to the diversity of production systems of Brazilian broiler including litter reuse.

This study aimed to present the concentrations of NH_3 and CO_2 in broiler houses with litter reuse for more than 10 production cycles and verify thermal comfort.

2.2. Materials and methods

The experiment was conducted in three commercial broiler farms located in southern Brazil between October 2014 and May 2015 during six weeks in every batch.

The birds used during the experimentation were males cobb 500 with an average growth period of 41 days.

These broiler rearing buildings examined in the study have small differences in litter and ventilation management broiler. Broiler houses are of the same integrated production plant, and the first batch analyzed started on the same day to reduce the differences in animal breed, slaughter age, body weight, and feeding regiment between broiler houses. The poultry buildings were selected as close as possible to each other to ensure that external climatic conditions were consistent. Climatic data for the region studied show that the coldest and warmest months are July (mean 15 °C) and January (mean 26.1 °C), respectively. Precipitation is lowest during summer and highest during winter. The average annual rainfall is 2000 mm.

2.2.1. Broiler houses and management

Three dark house (DH) systems with 1500 m² (DH1), 1200 m² (DH2), and 960 m² (DH3) had forced ventilation; nine exhaust fans each DH (flow of 44.000 m³ h⁻¹ each), evaporative cooling, and the lateral areas were closed off with double black polypropylene curtains.

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 in the first week to 27 °C after two weeks and finally to 22 °C during the end of the grow-out phase.

Houses had three automatic feeder lines through the length of the house and four automatic nipple water lines. The adopted average batch density was approximately 14 birds m⁻².

The brooding dimensions in first day were 12 x 25 m located in the center of the all houses and was increased dimensions to the total size of the house in around two weeks (0 to 14 days). In both houses, the heating was used from day 0 to 14 of the grow-out period and consisted of a stove (burned wood) with the heat distributed through metallic tubes.

2.2.2. Litter management

In all houses, broilers were reared with reused litter. Pine wood shavings were the original bedding material set on the house floor. The litter had been reused for 10 batches before starting this research. After slaughter of the broilers, the cake or upper compacted layer of litter was removed and calcium oxide (CaO) applied between batches in DH1, DH2 and DH3. The interval regular between batches was 6 to 10 days. One day before the animals enter, the brooding chamber was prepared in the center of housing with the addition of 2-cm wood shavings. When the birds reached between 14 days to 30 days, the litter was mixed daily.

2.2.3. Measurements

2.2.3.1. Environmental variables and Thermal comfort index

The parameters determined at each broiler house included air temperature, relative humidity, and air speed, being measured every week in the morning and in the afternoon.

Indoor and outdoor temperature and humidity ventilation rate were recorded with sensor type TESTO 177H1 and with a hot wire anemometer type TESTO 425.

Measurements were performed at three positions in the broiler house. The cooling pad is the first sampling point, the middle position was the lengthwise midpoint of the house, and the final position was located 30 m away from the middle toward the exhaust fans at the end of the house.

Enthalpy was determined using the equation described by Barbosa et al. (2007) (Equation 1):

$$H = 6.7 + 0.243 \times temp + \left\{ \frac{RH}{100} \times 10^{\frac{7.5 \times temp}{237.3 + temp}} \right\} \times 4.184 \quad (1)$$

where: H is enthalpy in kJ kg⁻¹ dry air; temp is dry bulb temperature in °C, and RH is relative humidity in percentage.

To characterize the thermal comfort zone for birds, the Enthalpy comfort index developed by Barbosa Filho et al., (2007) and the index proposed by Coldebella et al., (2015) were used.

The percentage within the daily comfort range was calculated, considering the comfort ranges proposed by Barbosa et al., (2007) and the ranges proposed by Coldebella et al., (2015) (based on weekly tracks). The result is displayed as an average percentage per batch for each reference. The thermal comfort percentage of each batch of chicken was calculated as follows (Equation 2):

$$Comfort(\%) = \frac{\sum x}{n} \quad (2)$$

Where: x is a variable equal to 0 if the enthalpy is outside the comfort range and equal to 100 if the enthalpy is within the comfort range; n is the total number of evaluations performed by all dataloggers in each batch.

2.2.3.2. NH_3 and CO_2 concentrations

Concentrations of gases NH_3 and CO_2 were measured weekly after sampling in bags (6-day sampling in each batch) in the morning and afternoon in terms of ppm. Outdoor air sampling was also carried out simultaneously. Gas concentrations in the bags were measured using a photoacoustic multigas analyzer (INNOVA 1412). In the period when the birds were in brooding chamber, the data were recorded only in the area occupied by the birds.

Bags were filled with a pump; the air sampling lasted for 30 minutes and was performed by walking through the entire length of the installation (figure 2.1). Subsequently to allow a delayed analysis of the air samples, the bags were stored in containers to maintain their stability and their representativeness and were taken to Embrapa Swine and Poultry, where concentration determination was performed.

These sampling bags are used to sample the ambient air in animal husbandry and on the exterior of buildings. These materials are inert to the compounds studied. They are best suited for air sampling in animal buildings to determine concentrations of NH_3 , CO_2 , N_2O , CH_4 and H_2O (HASSOUNA; EGLIN, 2015).

Figure 2.1 System used for air sampling, air pump and bag utilized in measurement.

2.2.3.3. Bird Performance

Monitoring the development of the birds in both breeding systems was conducted to evaluate possible influences of air quality and thermal comfort on the performance. Performance was evaluated using the body weight, feed intake, feed conversion, and mortality variables. In each batch, 100 birds were weighed so as to obtain the body weight and weight gain. Consumption was calculated as the difference between the supplied and spare food, and the feed conversion ratio was calculated by the total feed intake for weight gain. Mortality was calculated by the difference between the number of chicks housed and the number of chickens until loading. To measure the production efficiency reached by each batch, the production efficiency index (PEI) was used, which is obtained by Equation 3:

$$PEI = \frac{WG \times V}{FC} \times 100 \quad (3)$$

Where: WG is daily weight gain in kg, V is viability in percentage, and FC is feed conversion in kg kg⁻¹. Globally, this index evaluates the zootechnical indexes and is commonly used by the integrated poultry companies to remunerate the producer integrated ones (SANTOS et al., 2005).

2.2.4. Statistical analysis

All data obtained from measurement were statically analyzed by SAS, including descriptive statistic, analysis of variance. Significant correlations ($p < 0.05$) between air concentrations (NH₃ and CO₂) with environmental parameters (air temperature, humidity, enthalpy, air speed) were statistically evaluated utilizing Pearson's correlation.

To present the results to gas concentrations a statistical analysis was performed using the theory of mixed models for repeated measures, considering effects of: house, age in weeks, daytime and interaction effect between age and daytime using SAS Mixed Proc (XAVIER, 2000). The graph was produced using the Sigma Plot software.

2.3. Results

2.3.1. Environmental variables and thermal comfort index

Figure 2.2 shows the average results of air temperature observed in the dark houses studied. It is generally verified that, regardless of average by installation, daily temperature averages corresponding to the first week of life of the birds were always below the ideal bands of the thermal comfort zone recommended by Curtis (1983). That is, they were between 28 and 32 °C, but the target temperature recommended by agro industry only has not been reached in the last weeks. When the average temperatures per period (morning and afternoon) was observed for all batches and installations, it was noticed that the most critical period of the day in relation to cold stress is the morning period during the first week.

Figure 2.2 Indoor average temperature and recommended thermal comfort temperature.

Ideal bands for the thermal comfort for the first week of life of the poultry are between 32 and 35 °C and the second between 28 and 32 °C (Curtis, 1983), but the temperature target by agro industry was 32 °C in first day and decreased 0.5 °C until 29 °C in seventh day. During the first two weeks of accommodation, all premises assessed were below the comfort temperature range recommended by Curtis (1983), but the target temperature recommended by agro industry was achieved. However, when the averages observed in the third and fourth week being at comfortable conditions following the recommendations by Curtis, (1983), the target temperature recommended by agro industry was not achieved (Figure 2.2).

Critical moments in the behavior of temperature are the fifth and sixth weeks where high temperatures can cause heat stress. During the sixth week, it is clear that the thermal comfort conditions provided to the birds in the broiler houses are inadequate with an average temperature above 24 °C. These high temperatures can characterize a severe heat stress situation in birds, reflected in the comfort and animal welfare.

Figure 2.3 Indoor relative humidity and satisfactory range.

Indoor relative humidity inside the premises was higher the conditions recommended for the 4th, 5th, and 6th weeks (Figure 2.3). The high average RH values were due to rainy conditions, high outside relative humidity but also were due to high outside temperature and the use of cooling throughout the morning and afternoon in some batches, the relative humidity remained within the range of comfort only in the first week of accommodation. The RH values observed in the last weeks are higher than the recommended maximum limit for bird comfort, which is 70%.

In figure 2.4, the values observed for enthalpy and thermal comfort index are given (kJ kg^{-1} dry air). These indices were obtained from tables of enthalpy proposed by Barbosa Filho et al., (2007) and Coldebella et al., (2015).

Figure 2.4 Enthalpy averages in every broiler house and comfort bands recommended by Barbosa et al. (2007) and recommended by Coldebella et al. (2015).

Enthalpy average (Figure 2.4) was similar to the temperature (Figure 2.2). In Figure 2.4, it can be seen that the enthalpy change in the broiler house was above the conditions recommended for the fifth and sixth weeks and lower in the first week. The highest mean values were for the last week and were noted to be above the recommended value of 52.1 kJ kg⁻¹ (BARBOSA FILHO et al., 2007). The nearest enthalpy values of comfort were found in the 1st and 2nd weeks for index recommended by Barbosa et al., (2007) and 2nd, 3rd and 4th for index recommended by Coldebella et al., (2015). At the 5th and 6th weeks, heat stress may occur.

The percentage of comfort obtained for each batch is presented in the following table (2.1) and highlights the results observed in the graphs.

Table 2.1 Comfort percentage by enthalpy index proposed by Barbosa et al. 2007 and Coldebella et al., 2015 based on weekly measurements of air temperature and humidity.

Batch	DH1		DH2		DH3	
	Barbosa (2007)	Coldebella (2015)	Barbosa (2007)	Coldebella (2015)	Barbosa (2007)	Coldebella (2015)
1	48.67	60.87	39.43	30.35	24.36	48.04
2	26.21	49.68	17.42	46.81	31.42	61.59
3	30.91	56.55	27.10	58.16	32.52	60.36
4	55.67	70.18	35.67	68.04	-	-
Average	40.36	59.32	29.91	50.84	29.43	56.66

In table 2.2 is showed descriptive statistical analysis of carbon dioxide, ammonia, inside and outside temperature, humidity and airflow in broiler houses for all data.

Table 2.2 Descriptive statistical analysis of ammonia and carbon dioxide concentrations, temperature, humidity and air velocity.

Parameter	<i>n</i>	Arithmetic mean	Minimum	Maximum	SD
CO ₂ (ppm-v)	111	931	489	2.159	348
NH ₃ (ppm-v)	111	8.3	1.8	33.1	6
Temperature inside(°C)	111	26.9	19.1	35.3	3
Temperature outside(°C)	111	26.5	17.5	38.4	4
Humidity (%)	111	77.6	38.4	95	15.2
Airflow (m s ⁻¹)	111	0.9	0.05	3.9	0.7

SD standard deviation

2.3.2. Bird performance

According to the average values of food conversion (FC), feed intake (FI), mortality, and slaughter weight shown in Table 2.3, there is no difference from the F test between the values of these production performance rates among the dark houses assessed ($p < 0.05$).

Table 2.3 Performance variables of the birds in each dark house.

Performance variables	DH1	DH2	DH3
Feed conversion (kg kg ⁻¹)	1.62±0.07a*	1.59±0.03a	1.61±0.04a
Slaughter age (days)	40.8± 1.5 ^a	40 ± 1.7a	40.7± 0.6a
Feed intake (kg bird ⁻¹)	4.7±0.30 ^a	4.39±0.18a	4.4±0.04a
Mortality (%)	5.28±2.79 ^a	4.33±1.26a	3.90±1.51a
Slaughter weight (kg)	2.90±0.01 ^a	2.76±0.11a	2.72±0.07a
Production of index (PEI)	381±26.6 ^a	379±22.1a	377±13.5a

* Different lowercase letters in the same line indicate significant difference by the Tukey-Kramer test ($p \leq 0.05$).

The average final FI have values between 4.23 and 3.90 kg, respectively. The bird weight gain was between 455 and 484 grams per week, respectively.

2.3.3. NH₃ and CO₂ concentrations

Average concentrations observed each week for the all batches in DH1, DH2, and DH3 are presented in Table 2.4 and 2.5, in Table 2.6 are showed average NH₃ and CO₂ concentration and standard deviation by period of day for all batches.

In table 2.4 and 2.5 is possible observed that there was no difference between the houses.

Table 2.4 Arithmetic mean and standard deviation NH₃ concentrations by week in dark house evaluated.

	DH1	DH2	DH3
Weeks	(ppm-v)	(ppm-v)	(ppm-v)
1	5.4±2.1a	5.8±2.9 ^a	6.7±4 ^a
2	5.0±2.2a	5.2±2.2 ^a	11.1±9 ^a
3	12.4±6.6a	8.1±7.3 ^a	13.7±10a
4	12.3±6.7a	6.6±4.3 ^a	10.1±5.7a
5	8.7±6.5a	10.5±6.9a	5.7±2.1 ^a
6	9.3±7.5a	6.3±2.3 ^a	3.6±1 ^a

Different lowercase letters in the same line indicate significant difference by the Tukey-Kramer test ($p \leq 0.05$);

Table 2.5 shows the average carbon dioxide concentration values for the periods observed in the six weeks of production cycle.

Table 2.5 Arithmetic mean and standard deviation CO₂ concentrations by week in dark house evaluated.

	DH1	DH2	DH3
Weeks	(ppm-v)	(ppm-v)	(ppm-v)
1	1213±490a	903±491a	784±227a
2	1134±513a	996±373a	769±181a
3	1052±353a	990±358a	900±451a
4	1041±353a	902±207a	764±231a
5	830±187a	757±56 ^a	930±329 ^a
6	959±321a	722±39 ^a	766±63 ^a

Different lowercase letters in the same line indicate significant difference by the Tukey-Kramer test ($p \leq 0.05$).

Ammonia concentration values were higher in the morning (table 2.6), exceeding a maximum concentration of 25 ppm at week 4 when litter turnings were performed in DH2, but this concentration was only observed in one batch. Concentrations in the afternoon had a similar profile throughout the weeks. Significant correlation ($P \leq 0.05$) was observed between outside temperature, air velocity, and inside enthalpy, but the determination coefficient was less than 0.6.

In the results in Table 2.6, it can be seen that there is a daytime interaction effect between 1 and 5 weeks for NH₃. In the afternoon, there is no effect of age on concentrations of NH₃, unlike in the morning that showed differences ($P \leq 0.05$) between week 4 and 1, 2 and 6. Average values of concentration were higher between the third and fifth week, corresponding to the weeks in which the litter mixing was performed daily in the morning. During the period when no litter mixing was performed there were no differences between the weeks.

In all periods, carbon dioxide values found at the premises were within the acceptable limit of 3000 ppm (WATHES, 1999; NÄÄS et al., 2007) for poultry facilities.

The test of the mixed models for repeated measurements showed effect of age in weeks, daytime, and interaction between daytime and age in weeks.

When analyzed separately, there was a tendency for the first weeks to present higher concentration values compared to the last two weeks.

This can be seen by the significant difference between the second and sixth week, however, in the case of an experiment in a no controlled environment, some factors such as temperature, air velocity and relative humidity may have influenced gas concentrations (KILIC; YASLIOGLU, 2014).

Effects of other variables may explain the behavior of the concentrations between the weeks, since even though there is no significant ($p > 0.05$) difference between weeks 1,3,4 and 5 it is possible to observe that the mean value of the concentrations indicates the tendency of higher values between 1 and 4 weeks with the exception of 3 weeks which may have been affected by an external factor. As shown in Table 2.6, there was statistical difference among evaluation shift.

Higher CO₂ concentration values were observed in the mornings because probably the temperatures and air velocity were lower. The highest concentration was found in the second week and then decreased (Table 2.6).

While the birds are known to be responsible for the production of most of CO₂ in the broiler house and there is positive correlation with age and concentration, this behavior was not observed, probably due to increased air exchange rate to maintain the most suitable conditions for the comfort of the animals and other variables that affect the concentrations.

Table 2.6 Averages and standard errors of ammonia and carbon dioxide concentrations by period of the day and age of all data.

Weeks	CO ₂ (ppm-v)			NH ₃ (ppm-v)		
	Morning	Afternoon	Daily	Morning	Afternoon	Daily
1	1220±154abA	764±87aB	992± 101	7.78±1.09bcA	4.15±0.60aB	5.9±0.7
2	1262±175aA	751±47aB	1007± 110	7.59±1.90bcA	3.87±0.63aB	5.7±1
3	968±129abA	735±110aB	851± 88	13.22±3.63abcA	6.09±1.82aB	9.6±2.2
4	1195±130abA	780±47aB	987± 82	16.74±2.56aA	7.16±1.06aB	11.9±1.7
5	967±73abA	870±87aB	919± 56	12.09±2.07abA	8.19±1.51aB	10.1±1.3
6	803±69bA	763±36aA	784± 39	6.53±1.55cA	5.45±0.77aA	6±0.8

Different lowercase letters in the same column indicate significant difference by the Tukey-Kramer test ($p \leq 0.05$); Different capital letters in the same line indicate difference by the F test ($p \leq 0.05$).

The maximum concentrations observed for CO₂ did not exceed 2159 ppm, indicating that the management conditions (ventilation) ensured good air quality conditions for animals when considering CO₂. There is a correlation between the CO₂ concentration and outside temperature, inside enthalpy, air velocity ($p < 0.05$), but the determination coefficient was less than 0.6.

2.4. Discussion

2.4.1. Environmental variables and thermal comfort index

According to the results presented in the figure 2.2, the conditions of thermal comfort for the animals in some moments of first week are inferior to the satisfactory recommendation in literature (CURTIS, 1983). However, as the agro industry recommends target temperature lower in the first weeks, it is perceived that these temperature

values already has been altered by the own chain of production. Indicating that temperature bands considered optimal in accordance to literature may be outdated.

Cassuce et al., (2013) evaluated the temperature values recommended as thermal comfort for the initial period of growth of broilers, and observed that lower temperatures in the first few weeks did not appear to affect the performance of the animals. The comfort temperature bands that provide the best performance for the initial period of growth of broilers were 31.3 °C in the first week and between 26.3 and 27.1 °C for the second week. In this study, temperatures lower than the recommendations of Curtis (1983) in the first weeks do not seem to affect the performance of the chicks, reinforcing the need for new comfort temperature bands.

Indoor average temperature did not differ considerably from those in other studies in Brazil (CARVALHO et al., 2011) and other studies in farms in the Spain (CALVET et al., 2011).

Indoor relative humidity in last week was higher in this study than recommendation of Tinôco (2001) and Sarmiento et al., (2005), for which reported values satisfactory of 50 and 70%.

During evaluation of each broiler house, the comfort index was exceeded by 50% of the fifth and sixth week, a sign that the average enthalpy was above the amount proposed. Therefore, when analyzing the condition of stress, it can be seen that the mean values of energy may be higher than the comfort range for all operations evaluated. The enthalpy indicates the amount of energy contained in a mixture of dry air and water vapor. Therefore, the thermal exchanges are changed by modifying the relative humidity for the same temperature, due to the energy contained in the modified environment (ALBRIGHT, 1990).

As it can be observed in Table 2.1, the comfort indexes recommended by Coldebella et al., (2015), adjusted from the environmental conditions data and the performance results of 50 batches, encompasses broader comfort ranges providing better results for the percentage of batch comfort. When observing the results of the batch 4 in DH1, it can be seen that the enthalpy bands of comfort proposed by Barbosa et al., (2007) indicate that the environmental conditions maintained in this facility during this period would meet the comfort conditions in approximately 13 days. On the other hand, when considering the recommendations of Coldebella et al., (2015), 56% of batch period were in comfort range, i.e. approximately 23 days. When considering the results of weight gain and feed conversion observed, the amplitude of the environmental comfort bands for enthalpy recommended by Coldebella et al., (2015) seem quite realistic since the performance indices are satisfactory and similar to those found in other studies (DAMASCENO et al., 2010).

However, when considering the IEE and the average comfort percentage of the batches a significant correlation was not observed between these two variables, as was observed in the Coldebella et al., (2015) when performing the index adjustment. However, more repetitions are required to perform this correlation, and other studies are needed to identify the feasibility of the index proposed by Coldebella et al., (2015). The development of new indices is fundamental because the recommended and widely used thermal comfort indexes were developed on parameters of thermal and environmental comfort based on information from 80s, produced in conditions different from the current conditions of production.

In addition, the results observed in relation to the average comfort percentage of the batches (33% and 55%) indicate that possible improvements related to the management of the environmental variables, as well as improvements in the insulation of the installations and the efficiency cooling systems, can result in higher comfort levels, thus improving the production efficiency.

Although there are reports that the exposure of animals to unfavorable thermal conditions affect animal performance (ABREU et al., 2000; OLIVEIRA et al., 2006; FARIA FILHO et al., 2006), rates of feed conversion

and weight gain obtained in this study were very close to the values found in other studies in which the animals were in comfort (table 2.2). These values are higher than those found by Damasceno et al., (2010) reporting weight gain of 445.4 grams per week in the evaluation on the effect of different cooling systems on the production performance of broiler chickens, mixed sex, Cobb.

Feed conversion average values determined during the experiment were approximately 1.60. According to Cobb-Vantress (2008), the FC for broilers of Cobb 500 is approximately 1.70. FC in this study was also better than found by Pereira (2006), who reported 1.76 and 1.79 when evaluating broilers of the same lineage with climatic control. These results suggest that although they have been submitted to high temperatures and outside of enthalpy comfort zone, the performance of the animals was unsatisfactory. This result may be related to the fact that usually the animals raised in dark houses have performance levels superior to conventional systems. Nowicki et al., (2011) compared the performance of broiler chickens raised in the conventional system and dark houses. They observed significant differences between the feed conversion rates and slaughter age between these two systems and concluded that birds raised in dark houses were slaughtered at a younger age and had higher feed efficiency.

2.4.2. NH₃ and CO₂ concentrations

Air quality is an important factor to be considered in poultry breeding as it has considerable impacts on the health of animals. While in Brazil, there are no legal limits for bird exposure, usually in production for export, but the 25 ppm limit suggested by some international studies is followed for ammonia. The average concentration of ammonia found in broiler houses is within the acceptable limits except for DH2 at fourth week in the morning. The average concentration of the 11 batches was 10.6 and 5.7 ppm for morning and afternoon, respectively.

The lowest concentrations observed in the afternoon can be explained by the influence of variables such as ventilation, outside temperature, and the absence of management practices such as litter turnings in the afternoon. Out of studies performed in Brazil, there are some studies that observed effect of the daytime period on NH₃ concentrations (MENEGALLI et al., 2009; OSORIO ROBSON et al., 2016). In addition, many international studies have found a temporal effect on gas concentrations (CALVET et al., 2011; GUTIÉRREZ-ZAPATA et al., 2016).

In the results in Table 3, it can be seen that there is a daytime interaction effect between 1 and 5 weeks. In the afternoon, there is no effect of age on concentrations of NH₃, unlike in the morning that showed differences ($p < 0.05$) between week 4 and 1, 2 and 6. Average values of concentration were higher between the third and fifth week, corresponding to the weeks in which the litter mixing was performed daily in the morning. During the period when the litter mixing was performed there were no differences between the weeks.

Osorio et al., (2016), in Brazil, recently published a study assessing the air quality in broiler houses with natural ventilation in winter during the first three weeks of the cycle. The author observed daily minimum concentration of NH₃ during a certain time in the afternoon during the first week of life of animals. The concentrations observed were between 40 and 55 ppm during morning and between 20 and 40 ppm in afternoon.

In addition, Calvet et al., (2011) found higher concentrations at night. They attributed it to changes in ventilation rates, which were higher in the warmest hours of the day and during the summer. They also found that NH₃ concentration and emission was negligible in the first days of the batch, increasing progressively. Gutiérrez-Zapata et al. (2016) assigned that the differences found in all these studies can be attributed, among others, to changes in ventilation rates, the ventilation system used, and differences in manure management, airflow helps

release NH_3 from poultry manure. However, NH_3 can be diluted by high speeds, promoting litter drying and limiting its formation (GROOT et al., 1998; ATTAPATTU et al., 2008; HARPER et al., 2010; MILES et al., 2011).

Gutiérrez-Zapata et al., (2016) observed that ammonia concentration fluctuations in time. The day started with high ammonia concentrations, then, decreased from around 10:00 until 18:00 h, and the lowest values observed were between 12 and 18 h. The air velocity presented variation inversely.

In this study, all data air velocity in afternoon was higher than observed values in the morning and ammonia concentration was lowest in afternoon.

Besides the concentration change throughout the day, other studies observed stratifications of concentration in the house and variation during the season. Miles (2008) measured the NH_3 concentration in three vertical heights (litter surface, the height of animals, and height of workers) at three different locations of broiler house (near the air inlet, middle, and near the exhaust) using four types of equipment for determining concentrations in two cycles. He observed differences between the two cycles evaluated for the concentration of NH_3 and its vertical and horizontal distribution. In summer conditions, there was a greater difference in the vertical and horizontal stratification of broiler house. Concentrations were higher the lesser the distance from the litter surface and closer to the exhaust. In cycle 2, in the winter, there was homogeneity of the concentrations in the installation both in relation to height and length. In conditions of cycle 2, winter and reused litter, concentrations varied between the range of 20 and 25 ppm. while concentrations ranged between 4 and 12.1 ppm in cycle 1. The author suggests that there was stagnation of the atmosphere due to low air velocity in cycle 2 and, consequently, low rate of air renewal.

The air sampling, in this study, included the entire length of the broiler house, then, the reduction of a possible effect of horizontal stratification in the concentrations can be considered.

In this study, the average concentration was 8.3 ± 6 ppm and maximum was 33.1 ppm close to those observed by Zapata-Gutierrez et al. (2016) and lower than those observed by Osorio et al., (2016) in a poultry house naturally ventilated during the first phase of life of broilers in the winter period. For Zapata-Gutierrez et al., (2016), the average was 5.94 ± 3.83 , and the maximum was 31.70 ppm in naturally ventilated caged-egg facility.

Redwine et al., (2003) in the summer in tunnel- ventilated broiler houses observed the highest concentration on the thirty-second day of 15 ppm, in last week the concentrations decreased.

Results from Green et al., (2007) supported the concept that the ventilation driving force varies with weather for all systems monitored. In winter months, ventilation to control ammonia levels is more critical for the health of birds and workers. In summer months, control of temperature rise is more critical for prevention of heat stress.

Correlations have been observed between the concentration of NH_3 and environmental variables, enthalpy, temperature, and air velocity ($p < 0.05$), but the coefficients of determination were lower (0.3 - 0.6), which indicates a degree of linear relationship between these variables, while one cannot explain the other. In the international literature there are reports of correlation between concentrations and environmental variables. A strong correlation was observed by Corkery et al., (2013) between the relative humidity and NH_3 ($R^2 = 0.86 - 0.92$). Although, Seedorf et al., (1999) also observed a relationship between concentration and relative humidity in broiler house. These authors believe that to determine all process interactions to account for ammonia concentrations in animal facilities, is necessary to analyze many variables.

In this study, there was no correlation with the humidity, but there was correlation to enthalpy, which is calculated through the air humidity, atmospheric pressure, and temperature. This result would be an important

finding if there was a high coefficient of determination between these data, as the drivers of the thermal environment installed in the dark house typically use the enthalpy to drive the cooling system (pad cooling) and determine the amount of exhaust fans needed for operation. This would establish NH_3 concentrations for each enthalpy range allowing greater control of NH_3 concentrations by producers. Thus, the development of further studies in laboratory to verify possible links between these two variables, as well as covering the diversity of production systems, is required. Moreover, further investigations should focus on multivariate data analysis to determine interactions among all process parameters.

In this study, the daily average air concentration of ammonia was lowest in week 1 (5.9 ± 0.7 ppm), close to the value (4 ppm) found by Vucelino et al., (2007) in new litter.

The values of ammonia concentration were more similar between the houses in the first and second week. From the third week onwards, the differences were greater, probably due to the influence of the handling of each producer in relation to the litter turning and open of the air intake and operation of the pad cooling. Although, when it was tested the effect of the broiler house on the concentrations, no significance was observed.

The average daily concentration of ammonia increased significantly in week 3 and week 4 (9.6 ± 2.2 and 11.9 ± 1.7 ppm, respectively). In first week the birds were placed onto a new layer of litter (pine wood shavings), this aspect can have insured nitrogen losses. The air concentration of ammonia increased in week 3, 4 and 5 which could be associated with the increased in animal age and animal activity. The increased significantly observed in morning average of week 3 and 4 could be associated with litter turning. This rise in daily average concentrations of 3, 4 and 5 weeks is similar the result observed by Vucelino et al., (2007).

As noted for NH_3 concentrations in the afternoon, for CO_2 , there was no difference between age in weeks and the concentration of gas.

In all periods, carbon dioxide values found at the premises were within the acceptable limit of 3000 ppm (WATHES, 1999; NÄÄS et al., 2007) for poultry facilities. The maximum concentrations observed for CO_2 did not exceed 2159 ppm, indicating that the management conditions (ventilation) ensured good air quality conditions for animals when considering CO_2 . Average concentrations was 931 ± 348 ppm.

Miles et al., (2014) observed average concentration of CO_2 of 707 ± 227 ppm in highest ventilation rate and greatest average concentration (2342 ± 757 ppm) in lower ventilation rate. This author also conducted your research in tunnel-ventilated house with litter reused during batches 9 through 13.

Menegali et al., (2005) also observed higher concentrations of CO_2 in the morning. Evaluating two ventilation systems, positive and negative pressure, these authors observed concentrations close to 1900 ppm in the system with negative pressure and exceeding 2300 ppm in the system with positive ventilation in the morning. Although they not have observed significant differences between the systems, they suggest that concentrations are directly related to air renewal rate and outdoor temperatures.

2.5. Conclusions

Ammonia and carbon dioxide concentrations observed during the productive cycles did not exceed the recommendations of 25 ppm for ammonia and 3000 ppm for carbon dioxide. Average ammonia concentration was 8.3 ± 6 ppm and 931 ± 348 ppm for carbon dioxide.

Even with extended litter reuse, NH_3 and CO_2 concentrations agree well with other studies that utilized new litter or reused litter by fewer batches.

The average values of enthalpy observed in the last weeks of the production cycle were higher than 65 kJ kg dry air⁻¹. Although the values of enthalpy are above the recommended comfort ranges in the last weeks no was unsatisfactory index of productivity.

References

- ABREU, P.G.; BAETA, F.C.; ABREU, V.M.N. et al. Desempenho produtivo e bioeconômico de frangos de corte criados em diferentes sistemas de aquecimento. **Revista Brasileira de Zootecnia**, Viçosa, v.29, n.1, p.159-167, 2000.
- ABREU, V. M. N.; ABREU, P. G. Os desafios da ambiência sobre os sistemas de aves no Brasil. **Revista Brasileira de Zootecnia**, Viçosa. v. 40, n. 2, p. 1-14, 2011.
- ALBRIGHT, L.D. Environmental control for animals and plants. **ASABE**, St. Joseph, 318 p. 1990.
- ALENCAR, M. C. B.; NÄÄS, I. DE A.; GONTIJO, L. A. Respiratory risks in broiler production workers. **Revista Brasileira de Ciência Avícola**, Campinas, v.6, n.1, p.23-29, 2004.
- ASSOCIAÇÃO BRASILEIRA DE PROTEÍNA ANIMAL - ABPA. **Relatório anual 2015**. Disponível em: <www.abpa-br.com.br/>. Acesso em: 25 jan. 2016.
- ATAPATTU N.S.B.M, SERENATA D, Belpagodagamage UD. Comparison of ammonia emission rates from three types of broiler litters. **Poultry Science**, Oxford, v.87, n.12, p.2436–40, 2008.
- BARBOSA FILHO, J.A.D.; VIEIRA, F.M.C.; GARCIA, D.B. Mudanças e uso das tabelas de entalpia. Piracicaba, 2007. Disponível em: <http://www.nupea.esalq.usp.br>. Acesso em: 15 jun. 2015.
- BOTTCHEER, R.W.; BAUGHMAN, G.R.; GATES, R.S.; TIMMONS, M.B. Characterizing efficiency of misting systems for poultry. **Transactions of the ASAE**, St. Joseph v.34, p.586-590, 1991.
- CALVET, S.; CAMBRA-LÓPEZ, M.; BLANES-VIDAL, V.; ESTELLÉS, F.; TORRES, A.G. Ventilation rates in mechanically-ventilated commercial poultry buildings in Southern Europe: measurement system development and uncertainty analysis. **Biosystems Engineering**, Amsterdam, v.30, p.423-432, 2010.
- CALVET, S.; ESTELLÉS, F.; CAMBRA-LÓPEZ, M.; TORRES, A.G. Characterization of gas emissions from a Mediterranean broiler farm. **Poultry Science**, Oxford, v. 90, p. 534-542, 2011.
- CARVALHO, T. M. R.; MOURA, D. J.; SOUZA, M. Z.; SOUZA, G. S.; BUENO, L. G. F. Qualidade da cama e do ar em diferentes condições de alojamento de frangos de corte. **Pesquisa Agropecuária Brasileira**, Brasília, v.46, n.4, p. 351-361, 2011.
- CASSUCE, Déborah C. et al . Thermal comfort temperature update for broiler chickens up to 21 days of age. **Engenharia Agrícola**, Jaboticabal, v. 33, n.1, p. 28-36, 2013.
- COBB-VANTRESS BRASIL. Manual de manejo de frangos de corte. **Cobb Vantress**, Guapiaçu, 66p, 2008.
- COBLE D.J.; FLEMING D.; PERSIA M.E., RNA-seq analysis of broiler liver transcriptome reveals novel responses to high ambient temperature. **BMC Genomics**. v.15, n.1, p.1084, 2014.
- COLDEBELLA, A.; ABREU, P. G. de; SANTOS FILHO, J. I. dos. Faixas de conforto térmico em função da idade dos frangos. In: CONGRESSO BRASILEIRO DE AVICULTURA E SUINOCULTURA - SIAVS, 2015, São Paulo. **Anais...** ABPA, São Paulo, p. 203-206, 2015.
- CORKERY, G. et al. Monitoring environmental parameters in poultry production facilities. Computer Aided Process Engineering, In: CAPE FORUM GRAZ UNIVERSITY OF TECHNOLOGY, 2013. **Proceedings...** Graz, 2013.

- COUFAL C.D., CHAVEZ C., NIEMEYER P.R., CAREY J.B. Nitrogen emissions from broilers measured by mass balance over eighteen consecutive batches. **Poultry Science**, Oxford, v.85, p.384–391, 2006.
- CURTIS, S. E. **Environmental management in animal agriculture**. The Iowa State University, Ames, 410p, 1983.
- DAMASCENO, F. A.; YANAGI JÚNIOR, T.; LIMA, R. R.; GOMES, R. C. C.; MORAES, S. R. P. Avaliação do bem-estar de frangos de corte em dois galpões comerciais climatizados. **Ciência e Agrotecnologia**, Lavras, v.34, p.1031-1038, 2010.
- ESTELLÉS F, CALVET S, OGINK NWM. Effects of diurnal emission patterns and sampling frequency on precision of measurement methods for daily ammonia emissions from animal houses. **Biosystems Engineering. Amsterdam**, v.107, n.1, p.16–24, 2010.
- FAIRCHILD, B. D. Environmental factors to control when brooding chicks. **Technical Bulletin 1287**, 2009. Cooperative Extension Service, Uni. of Georgia, GA. Disponível em: <http://www.caes.uga.edu/publications/pubDetail.cfm?pk_id=7388>. Acesso em 09 jun. 2016.
- FARIA FILHO, D.E.; ROSA, P.S.; FIGUEIREDO, D.F. et al. Dietas de baixa proteína no desempenho de frangos criados em diferentes temperaturas. **Pesquisa Agropecuária Brasileira**, Paraíba, v.41, n.1, p.101-106, 2006.
- FIEDLER A.M, MÜLLER H.J. Emissions of ammonia and methane from a livestock building natural cross ventilation. **Meteorologische Zeitschrift**, Stuttgart, Germany, v.20, n.1, p.59–65, 2011.
- FURTADO, D. A.; ROCHA, H. P.; NASCIMENTO, J. W. B. DO; SILVA, J. H. V. Índices de conforto térmico e concentração de gases em galpões avícolas no semiárido paraibano. **Engenharia Agrícola**, Campinas, v.30, p.993-1002, 2010.
- GATES, R.S.; ZHANG, H.; COLLIVER, D.G.; OVERHULTS, D.G. Regional variation in temperature humidity index for poultry housing. **Transactions of the ASAE**, St. Joseph v.38 p.197-205, 1998.
- GREEN A.R; WESLEY I.; TRAMPEL D.W; XIN H. Air quality and bird health status in three types of commercial egg layer houses. **Journal Applied Poultry Research.**, Oxford, v.18, p.605–621, 2009.
- GROOT P.W.G; METZ J.H.M.; UENK G.H; PHILLIPS V.R; HOLDEN M.R; SNEATH R.W.; Concentrations and emissions of ammonia in livestock buildings in Northern Europe. **Journal agricultural Engineering Research**. Amsterdam, v.70, n.1, p.79–95, 1998.
- GUTIÉRREZ-ZAPATA D.M.; GALEANO-VASCO L.F.; CERÓN-MUÑOZ M.F. Semiparametric Modeling of Daily Ammonia Levels in Naturally Ventilated Caged-Egg Facilities. **PLoS ONE**, San Francisco, v.11, n.1, 2016.
- HAI, L; RONG, D; ZHANG, Z.Y. The effect of thermal environment on the digestion of broilers. **Animal Physiology**. San Francisco, v.83, n.2, p.57–64, 2000.
- HAMRITA, T.K.; MITCHELL, B. Poultry housing control: A summary of where we are and where we want to go. **Transactions of the ASAE**, St. Joseph v.42, p.479-483, 1999.
- HARPER L.A; FLESCH T.K; WILSON J.D. Ammonia emissions from broiler production in the San Joaquin Valley. **Poultry Science**, Oxford, v. 89, p.1802-814, 2010.
- HERNANDES, R.; CAZETTA, J.O. Método simples e acessível para determinar amônia liberada pela cama aviária. **Revista Brasileira de Zootecnia**, viçosa, v.30, p.824-829, 2001.
- KNIXATOVA, M.; MIHINA, S.; BROUCEK, J.; KARANDUSOVSKA, I.; MACUHOVA, J.. The influence of litter age, litter temperature and ventilation rate on ammonia emissions from a broiler rearing facility. **Czech Journal. Animal. Science**. Czech Republic, v.55, n.8, p.337 345, 2010.

- KNIZATOVA, M.; BROUCEK, J.; MIHINA, S. Seasonal differences in levels of carbon dioxide and ammonia in broiler housing. **Slovak Journal of Animal Science**, Slovakia, v.43, p.105-112, 2010.
- KNOWLTON, K. Ammonia emissions: the next regulatory hurdle. **The Jersey Journal**, New Jersey, v.47, p.56-57, 2000.
- LIMA, K. A. O.; MOURA, D. J.; CARVALHO, T. M. R.; BUENO, L. G. F.; VERCELLINO, R. A. Ammonia emissions in tunnel-ventilated broiler houses. **Brazilian Journal of Poultry Science**, Campinas, v. 13, p. 265-270, 2011.
- MACARI, M.; FURLAN, R. L. Ambiência na produção de aves de corte. In: SILVA, I. J. O. (Ed.). Ambiência na produção de aves em clima tropical. **FUNEP**, Piracicaba, . v. 1, p. 31-87, 2001.
- MELUZZI, A.; SIRRI, F. Welfare of broiler chickens. **Italy Journal of Animal Science**, Pavia, v.8, n.1, p.161-173, 2009.
- MENEGALI, I.; TINÔCO, I. DE F. F.; BAÊTA, F. C.; CECON, P. R.; GUIMARÃES, M. C. C; 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**, Campina Grande, v.13, p.984-990, 2009.
- MENG L-H.; LI C.; LU, Q.-P.; ZHANG H-F.; MA J.-X.. Effect of Different Ammonia Concentrations on Broiler Welfare. **Acta veterinaria et zootechnica sinica**, China. Vol. 47 (8), p. 1574-1580, 2016.
- MILES, D.M., OWENS, P.R., ROWE, D.E. Spatial variability of litter gaseous flux within a commercial broiler house: ammonia, nitrous oxide, carbon dioxide, and methane. **Poultry Science**, Oxford, v.85, p. 167–172, 2006.
- MILES, D.M. Vertical stratification of ammonia in a broiler house. **Journal of Applied Poultry Research**, Oxford, v.17, n.3, p.348-353, 2008.
- MILES D.M; ROWE D.E; CATHCART T.C. Litter ammonia generation: Moisture content and organic versus inorganic bedding materials. **Poultry Science**, Oxford, v.90, n.6, p.1162–9, 2011.
- MIRAGLIOTTA, M.Y.; NÄÄS, I. de A.; MANZIONE, R.L.; NASCIMENTO, F.F. Spatial analysis of stress conditions inside broiler house under tunnel ventilation. **Scientia Agrícola**, Piracicaba, v.63, n.5, p.426-432, 2006.
- MOSQUERA J.; MONTENY G.J.; ERISMAN J.W. Overview and assessment of techniques to measure ammonia emissions from animal houses: the case of the Netherlands. **Environmental Pollution**, Amsterdam v.135, p.381–388, 2005.
- MOURA, D.J. Ambiência na produção de aves de corte. In: SILVA, I.J.O. (Ed.). Ambiência na produção de aves em clima tropical. 1.ed. Piracicaba: **FUNEP**, v.2, p.75-148, 2001.
- NÄÄS, I. DE A.; MIRAGLIOTTA, M.Y.; BARACHO, M. DOS S.; MOURA, D. J. DE. Ambiência aérea em alojamento de frangos de corte: poeira e gases. **Engenharia Agrícola**, Campinas, v.27, n.2, p.326-335, 2007.
- NAZARENO, A. C. et al. Bem-estar na produção de frango de corte em diferentes sistemas de criação. **Engenharia Agrícola**, Jaboticabal, v. 31, n. 1, p. 13-22, Feb. 2011.
- NAZARENO, A. C. et al. Avaliação do conforto térmico e desempenho de frangos de corte sob regime de criação diferenciado. **Revista brasileira engenharia agrícola ambiental**, Campina Grande, v. 13, n. 6, p. 802-808, 2009.
- NOWICKI, R.; BUTZGE, E.; OTUTUMI L. K.; JÚNIOR R. P.; ALBERTON L. R.; MERLINI L. S.; Desempenho de frangos de corte criados em aviários convencionais e escuros. **Arquivos Ciências Veterinárias Zoologia**, Maringá, v.14, p.25–28, 2011.

- OLANREWaju, H. A.; DOZIER, W. A.; PURSWELL, J. L.; BRANTON, S. L.; MILES, D. M.; LOTT, B. D.; PESCATORE, A. J.; THAXTON, J. P. Growth performance and physiological variables for broiler chickens subjected to short-term elevated carbon dioxide concentrations. **Poultry Science**, Oxford, v.7, n.8, p.738-742, 2008.
- OLIVEIRA, M.C. DE; ALMEIDA, C.V.; ANDRADE, D.O.; RODRIGUES, S.M.M. Teor de matéria seca, pH e amônia volatilizada da cama de frango tratada ou não com diferentes aditivos. **Revista Brasileira de Zootecnia**, Viçosa, v.32, p.951-954, 2003.
- OLIVEIRA, R.F.M.; DONZELE, J.L.; ABREU, M.L.T. et al. Efeitos da temperatura e da umidade relativa sobre o desempenho e o rendimento de cortes nobres de frangos de corte de 1 a 49 dias de idade. **Revista Brasileira de Zootecnia**, Viçosa, v.35, n.3, p.797-803, 2006.
- OSORIO R. H.; TINOCO I. F. F.; OSORIO, J. A. S.; MENDES L. B. Thermal environment in two broiler barns during the first three weeks of age. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v.20, n.3, p.256–262, 2016.
- OSORIO, R. H.; TINOCO I. F. F. ; OSORIO J. A. S.; SOUZA C. DE F.; COELHO, D.J. DE R ; DE SOUSA, F. C. Calidad del aire en galpón avícola con ventilación natural durante la fase de pollitos. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, PB, UAEA/UFCG. v.20, n.7, p.660-665, 2016.
- OWADA, A.N.; NÄÄS, I. de A.; MOURA, D.J. de; BARACHO, M. dos S. Estimativa de bem-estar de frango de corte em função da concentração de amônia e grau de luminosidade no galpão de produção. **Engenharia Agrícola**, v.27, p.611-618, 2007.
- PEREIRA, A.K. **Fatores térmicos ambientais e qualidade do ar no desempenho produtivo de frangos de corte criados em alta densidade sob sistemas de ventilação positiva**. 2006. 76p. Dissertação (Mestrado em Engenharia Agrícola) Universidade Federal de Viçosa, Viçosa, 2006.
- PIÓRKOWSKA K; ŻUKOWSKI K; NOWAK J.; POŁTOWICZ K.; ROPKA-MOLIK K.; GURGUL A. Genome-wide RNA Seq analysis of breast muscles of two broiler chicken groups differing in shear force. **Animal Genetics Utrecht** , Netherlands, v.47, n.1, p.68–80, 2015.
- REDWINE, J. S.; LACEY, R.; MUKHTAR, S.; CAREY, J. B. Concentration and emissions of ammonia and particular matter in tunnel-ventilated broiler barns under summer conditions in Texas. **Transactions of the ASABE**, St. Joseph, v. 45, p. 1101-1109, 2002.
- REECE, F. N.; LOTT, B. D.; DEATON, J. W. Ammonia in the atmosphere during brooding affect performance of broiler chickens. **Poultry Science**. Oxford, v.59, n.1, p.486-488, 1980.
- RITZ, C.W.; MITCHELL, B.W.; FAIRCHILD, B.D.; CZARICK, M. III; WORLEY, J.W. Improving in-house air quality in broiler production facilities using an electrostatic space charge system. **Journal of Applied Poultry Research**, Athens, GA, v.15, p.333-340, 2006.
- RONCHI, C. Principais práticas de manejo para aves recém nascidas. **Revista Aveworld**, São Paulo, ano 1, n.6, p.26-30, 2004.
- SAINSBURY, D. Poultry Health and Management. **Blackwell Scientific**. London, U.K. . 3 ed. 214p, 1992.
- SANTOS, T. M. B.; LUCAS, J. J.; SAKOMURA, N. K. Efeitos de densidade populacional e da reutilização da cama sobre o desempenho de frangos de corte e produção de cama. **Revista Portuguesa de Ciências Veterinárias**, Lisboa, v. 100, p. 45-52. 2005.

- SARMENTO, L. G. V.; DANTAS, R. T.; FURTADO, D. A.; NASCIMENTO, J. W. B. DO; SILVA, J. H. V. Efeito da pintura externa do telhado sobre o ambiente climático e o desempenho de frangos de corte. **Agropecuária Técnica**, Paraíba, v.26, n.2, p.117-122, 2005.
- SAVASTANO JÚNIOR, H.; SILVA, I.J.O.; LUZ, P.H.C.; FARIA, D.E. Desempenho de alguns sistemas de cobertura para aviários. **Engenharia Rural**, Piracicaba, v.8, n.1, p.1-11, 1997.
- SEEDORF J.; HARTUNG J. Survey of ammonia concentrations in livestock buildings. **Journal of Agricultural Science**, Toronto, v.133, p.433–437, 2002.
- TASISTRO A.S.; KISSEL D.E.; BUSH P.B. Spatial variability of broiler litter composition in a chicken house. **Journal of applied poultry research**, Oxford, v.13, p.29-43, 2004.
- TINÔCO, I. F. F. Avicultura industrial: novos conceitos de materiais, concepções e técnicas construtivas disponíveis para galpões avícolas brasileiros. **Revista Brasileira de Ciência Avícola**, Campinas, v.3, n.1, p.1-26, 2001.
- VUCEMILO, M., K.; KATKOVIC, B.; VINKOVIC, S.; JAKSIC, K.; GRANIC, A.; MAS, N. The effect of animal age on air pollutant concentration in a broiler house. **Czech Journal Animal Science**, Czech Republic, v.52, p.170–174, 2007.
- WATHES, C. M. Strive for clean air in your poultry house. **World Poultry**, Doetinchem, Netherlands v.15, n.3, p.17-19, 1999.
- WEI F.X.; HU X.F.; SA R.N.; LIU F.Z.; LI S.Y.; SUN Q.Y. Antioxidant capacity and meat quality of broilers exposed to different ambient humidity and ammonia concentrations. **Genetics Molecular Research**, Ribeirão Preto, v.13, n.2, p.3117–3127, 2014.
- WHEELER, E. F.; CASEY, K. D. ; ZAJACZKOWSKI, J. S. ; TOPPER, P. A. ; GATES, R. S. ; XIN, H.; LIANG, Y.; TANAKA, A. Ammonia emissions from U.S. poultry houses: Part III – Broiler houses. Research triangle park, **ASAE**, St. Joseph, p.159–166, 2003.
- WINDHORST, H.-W. Changes in poultry production and trade worldwide. **Poultry Science Journal**, Oxford, v.62, n.4, p.585–602. 2006.
- XAVIER, L. H. **Modelos univariado e multivariado para análise de medidas repetidas e verificação da acurácia do modelo univariado por meio de simulação**. 2000. 91 p. Dissertação (Mestrado) – Programa de Pós-Graduação em Estatística e Experimentação Agronômica, Escola Superior de Agricultura “Luiz de Queiroz”, Universidade de São Paulo. Piracicaba. 2000.
- YI B.; CHEN L.; SA R.; ZHONG R.; XING H.; ZHANG H. High concentrations of atmospheric ammonia induce alterations of gene expression in the breast muscle of broilers (*Gallus gallus*) based on RNA-Seq. **BMC Genomics**. London, v.17 p.598, 2016.
- ZHANG G.; STRØM J.S.; LI B.; ROM H.B.; MORSING S.; DAHL P. Emission of ammonia and other contaminant gases from naturally ventilated dairy cattle buildings. **Biosystems Engineering**. Amsterdam, v.92, n.3, p.355–64, 2005.
- ZHU Z.; DONG H.; ZHOU Z.; XIN H.; CHEN Y. Ammonia and greenhouse gases concentrations and emissions of a naturally ventilated laying hen house in Northeast China. **ASABE**, St. Joseph, v.54, n.3, p.1085–91, 2011.

3. CARBON AND NITROGEN MASS BALANCE IN BROILER HOUSES

ABSTRACT

The global search for the sustainability of production processes, knowing the path traveled by the elements, their efficiency, and dynamics, allows one to identify solutions to reduce their wastes and to minimize the input consumption. Knowing the mass flows during the production cycle of broilers allows one to understand the utilization, transformations, accumulation, and losses/dissipation of mass. This study aimed to quantify, sample, and analyze all inputs and outputs of nitrogen and carbon elements by quantifying input and output variables of the system in four batches of broiler chickens conducted in three dark houses in litter reused. Feed intake and feed composition, chemical composition of poultry litter, and poultry were counted as system inputs. The slaughtered birds, the accumulated elements in litter at the end of the batch, and the gaseous emissions were considered the outputs of the system. Mass balance was validated by phosphorus (stable element) and showed average error lower than 10%. The loss of carbon represented 61% of the carbon that was put into the system through the feed and corresponded to $1.16 \pm 0.18 \text{ kg bird}^{-1}$. The lost nitrogen represented 31% put in by the feed and corresponded to $46.7 \pm 0.02 \text{ g bird}^{-1}$. The litter reuse for two years seems to significantly increase the losses of N and C when compared to the losses observed in other studies conducted with a new litter.

Keywords: Nitrogen; Carbon; Consumption; Losses; Litter reuse

3.1. Introduction

Brazilian animal production has reached unprecedented levels in recent years, especially in relation to broiler breeding (ABPA, 2015). This is mainly due to the increased demand for animal products in developed countries. In this scenario, small farms with traditional production systems have been replaced by confined production facilities with high production densities. These intensive production systems present better economic results but are known for their negative impacts on the environment (FAO, 2006) through the waste production in large quantities and emission of ammonia and greenhouse gases.

In Europe, for example, the animal production sector strongly influences the cycle of elements, such as nitrogen, because large amounts of nutrients, water, and energy are related to this sector (ERISMAN et al., 2008).

In this sense, knowing the flows of elements is of fundamental importance for the management of production. The approach of mass balance at the level of animal production is a method recommended by several authors to determine and identify nutrient rates and gaseous element losses. The proposed mass balance calculation is usually used to monitor the efficiency element use as a relation between the inputs and outputs. Several studies have already been developed with the objective of identifying nitrogen flows and their budget in broiler production (PATTERSON et al., 1998; COUFAL et al., 2006; MEDA et al., 2015; MOORE et al., 2011; MITRAN et al., 2008; DONG et al., 2011; BORBRUTZKI et al., 2013).

For Kratz et al. (2004), this technique is very interesting because besides the knowledge of flows, it allows the comparison of results between different systems of production of broilers and facilitates the identification of possible improvements in the systems.

The main objective of the studies that used the mass balance in the production of broilers was to identify the nitrogen fluxes. However, the mass balance applies to any element, highlighting carbon, phosphorus, and water besides nitrogen, which is also used to calculate the airflow in animal facilities with natural ventilation through the CO₂ balance.

Dong et al., (2011) determined carbon and nitrogen losses by the mass balance in broiler production in cages. Xin et al., (2009) determined airflow in broiler houses with natural ventilation through the CO₂ balance. In addition, the mass balance is often used as a method that allows the verification of results obtained through other methodologies, especially with regard to the emission of gases (HAUSSOUNA; EGLIN 2015).

The variables in broiler houses that affect the flow of elements and, consequently, alter the results of the mass balance are the most significant inputs and outputs. Litter and animal feed can have strong influence on the flow of nutrients. In mass balances, feed normally corresponds to 99% of the mass input, and the availability of its nutrients affect the efficiency of use by the animals (BOBRUTZKI et al., 2013). In contrast, the litter conditions can affect the distribution of the outputs depending on the production conditions. Multiple litter reuse, excessive moisture content, and other aspects can influenced of mass balance. When litter reuse is practiced, the greater concentration of nutrients in the litter can alter both the input fractions and the output fractions in relation to the other variables.

In this sense, objective of this study was to account for nitrogen, carbon, and phosphorus inputs and outputs in the production of broilers and to identify their losses during four production batches in three dark house.

3.2. Materials and methods

The study was conducted in commercial houses of the dark house type located in Southern Brazil with 1500 m² (DH1), 1200 m² (DH2), and 960 m² (DH3) using forced ventilation, exhaust fans (flow of 44,000 m³ h⁻¹ each), evaporative cooling, and the lateral areas were closed off with double black polypropylene curtains as described in Chapter 2.

3.2.1. Animals

The birds used during the experimentation were males *Cobb* 500 and *Ross*. Birds were grown to approximately 2.8 kg, with an average growth period of 41 days. The average mortality factor was 4%.

3.2.2. Animal nutrition

Feed and water were provided *ad libitum*, following the recommendations of integrated agro-industry. Water was available in nipple drinkers. Every week and at slaughter, the birds and the feed were weighed to determine the average body weight and the average consumption. Mortality was record daily for correction of the average consumption and average final weight.

Analyzed chemical compositions of each diet are given in Table 3.1. Water consumption was measured by water meters at the end of each batch.

Table 3.1 Average chemical composition of diets in broiler houses.

Diets	Initial			Grower I			Grower II			Finisher			Slaughter		
	DH	DH	DH	DH	DH	DH	DH	DH	DH	DH	DH	DH	DH	DH	DH
compostion	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Total N (g kg ⁻¹)	38.8	37.1	38.0	38.1	37.8	38.0	35.1	34.5	31.6	32.5	31.7	32.6	29.2	29.2	30.6
Total C (g kg ⁻¹)	40.4	40.4	42.2	39.8	40.7	39.1	41.0	41.0	40.6	40.8	40.6	40.0	40.8	41.0	40.3
Total P (g kg ⁻¹)	7.7	6.9	6.1	8.7	8.2	8.0	6.0	6.4	5.4	5.3	5.4	5.3	5.2	5.8	6.1
DM (%)	88.4	87.8	89.8	89.2	89.4	90.4	89.9	90.8	90.4	89.7	89.0	90.6	89.4	89.2	91.0

3.2.3. Litter conditions

In both houses, broilers were reared on reused litter. Pine wood shavings were the original bedding material set on the house floor, and the litter had been reused from batches 11 to 17 for this research. After slaughtering the broilers, the cake or upper compacted layer of litter was removed and the application of calcium oxide (CaO) was performed between batches. The standard interval between batches was 6 to 10 days with opening of the curtains for ventilation in DH1 and DH3. In DH2, the house remained closed. One day before the animals enter, the brooding chamber was prepared in the center of housing with the addition of 2-cm pine wood shavings. When birds reached 14 days up to 30 days, the litter was mixed daily.

Every week and near the end of each batch, litter samples (approximately 1 kg) were collected. Samples were analyzed for moisture, pH, and nutrient content (nitrogen, carbon and phosphorus). Samples collected before the first batch were subjected to the same analyses. Moisture was determined by loss in weight after drying bedding samples for 48 h at 65 °C, and pH was measured by standard methodology (APHA, 1998). Carbon and nitrogen nutrients total were determined via combustion analysis (NELSON; SOMMERS, 1982), in elemental analyzer of C and N.

3.2.4. N, C, and P balance

In this study, the weight of all inputs and outputs was accounted for as accurately as possible. The difference between the inputs and outputs was then assumed to be lost from the broiler house to the environment (figure 3.1).

Figure 3.1 Mass balance for broiler houses.

For each element (N, P, or C noted X hereafter), total excretion ($X_{total_excretion}$, kg) was calculated using Eq. (1) from the difference between total ingestion ($X_{ingestion}$, kg) and body deposition in slaughtered and dead birds (X_{body} , kg). Body deposition for N, P, and C was calculated considering average body contents given by Itavi (2013) and shown in the table 3.2.

$$X_{total_excretion} = X_{ingestion} - X_{Body} \quad (1)$$

$$X_{retention_litter} = \Delta X_{litter} \times \left(\frac{age_{slaughter}}{age_{batch}} \right) \quad (2)$$

Where: X_{litter} is retention of nitrogen, carbon, or phosphorus in litter, $age_{slaughter}$ and age_{batch} are slaughter age adjusted for the mean and age of slaughter of batch, respectively.

The depth of the litter was measured each week in several points of the broiler houses. In 1 m², the depth of the litter was determined and the total mass litter in this area was determined. After, the mass determined with the mass estimated by the phosphorus with total excretion and concentrations in the litter (C_{litter}) at the end of the batch was compared (Eq. 3). The default was calculated (equation 4) considering ingestion, deposition, and accumulation in litter.

$$M_{litter} = \frac{X_{total_excretion}}{C_{litter}} \quad (3)$$

$$Default = X_{ingestion} - (X_{body} + X_{retention_litter}) \quad (4)$$

Table 3.2 Body deposition coefficient given by Itavi (2013) and used in the calculation of mass balance to determine the body mass of carbon, nitrogen and phosphorus in slaughtered and dead birds.

	P (g kg body mass ⁻¹)	C (g kg body mass ⁻¹)	N (g kg body mass ⁻¹)
Broilers	5.8	175	29

Overall inputs and litter samples for non-volatile P were used to calculate and check the mass balance of housing. According to Paillat et al., (2004), P is not volatilized and poorly soluble so it can be used to determine losses of other elements.

3.3. Results

3.3.1. Litter conditions

The litter dry matter decreased on average from 76% to 68 % during the development of the production batch. Typically, the increase in moisture content from the beginning to the end of the batch was between 6 and 10% in all production batches. The pH was alkaline during all batches and presented a small variation between 8 and 8.9. The initial C:N ratio between the batches varied between 10 and 15. This low C:N ratio is directly related to the number of litter reuses, which is equivalent to a period between 1.5 and 2 years of reuse, which is similar to matured compost.

3.3.2. Mass balance

Mass balance was performed for each batch based on the chemical composition of the feed and litter, together with the estimation of body retention of the nutrients.

Summaries of the data collected during this study are presented in Tables 3.3 and 3.4. In table 3.3, the data are showed for 11 batches, highlighting the input and output fractions of each variable and Table 3.4 showed mass balance average of all batches.

Table 3.3 Nitrogen and carbon mass balance in the studied broiler batches. The nitrogen and carbon losses were due to volatilization of gases NH_3 , N_2O , CO_2 and CH_4 .

Inputs/Outputs	DH1				DH2				DH3		
	1	2	3	4	1	2	3	4	1	2	3
Nitrogen inputs (g bird⁻¹)											
Litter	132.1	177.4	201.7	229.1	127.5	132.5	145.9	161	339.1	350.6	379.8
Feed	168.6	162.5	165.1	150.9	153.7	153.2	132.3	135.6	146.2	151.8	142.4
Nitrogen outputs (g bird⁻¹)											
Accumulation	84.2	77.6	83.9	78	79.9	78.2	76.4	77.4	78.5	79.8	74.5
Litter	173.5	219.7	234.1	235.2	149	150.2	162.8	174.5	371.3	382.7	403.9
loss	43	42.6	48.7	66.7	52.3	57.3	39	44.7	35.5	39.9	43.9
Carbon inputs (kg bird⁻¹)											
Litter	1.6	2	2.3	2.5	1.48	1.6	1.8	1.8	3.7	3.9	4.23
Feed	2	2	2	1.9	1.8	1.8	1.8	1.8	1.8	1.8	1.7
Carbon outputs (kg bird⁻¹)											
Accumulation	0.5	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Litter	1.99	2.5	2.6	2.6	1.7	1.83	1.99	1.9	4.25	4.43	4.29
loss	1.11	1.1	1.23	1.41	1.17	1.16	1.21	1.34	0.84	0.87	1.24

In Table 3.2, it is possible to observe the weight of each input and output variable for the mass balance. It should be noted that the young birds were not presented as an input because they were considered as an output. The concentration of N and C in the litter at the beginning of each batch (g bird⁻¹ or kg bird⁻¹) was presented in relation to the number of birds housed. This concentration was increasing among batches for both nitrogen and carbon.

Table 3.4 Average variables of phosphorus, carbon and nitrogen balance.

Variables	Mean $\pm$ standard deviation		
	Phosphorus	Carbon	Nitrogen
	(g bird ⁻¹)	(kg bird ⁻¹)	(g bird ⁻¹)
Feed	27.64 $\pm$ 3.09	1.89 $\pm$ 0.10	151.17 $\pm$ 11.56
Accumulation	15.80 $\pm$ 0.58	0.48 $\pm$ 0.02	78.99 $\pm$ 2.92
Default	1.18 $\pm$ 1.01	1.16 $\pm$ 0.18	46.76 $\pm$ 9.05
Error prediction	1.30 $\pm$ 0.84	-	-
Error prediction	9.59 $\pm$ 5.76	-	-

values represent: mean (n = 11) $\pm$ standard deviation

According to Table 3.4, the loss of carbon represented 61% of the carbon that was input to the system through the feed and was 1.16 kg bird⁻¹. The lost nitrogen represented 31% of what was ingested by the feed and corresponded to 46.7 g bird⁻¹. The estimated accumulation in birds was 480 $\pm$ 20 g bird⁻¹ and 78.9 $\pm$ 2.9 g bird⁻¹ for carbon and nitrogen, respectively. Was calculated the retention of N and C in the litter in relation to the estimation of the fractions excreted in each batch (not shown in the table). The N retained in the litter was 25.4 $\pm$ 11.6 g bird⁻¹ and accounted for 35.1% of the excretion. For carbon, it was considered that 43% of the ingested and non-accumulated in tissue fraction was lost by the animals breathing, so 250 $\pm$ 90 g bird⁻¹ representing 13.2% of the consumption was retained in litter. The N and C retained in the litter presented higher variation between the batches and broiler houses.

The nitrogen loss varied between 35.5 and 66.7 g bird⁻¹. Only in DH3 was observed an increase in nitrogen loss according of litter reuse.

For the carbon loss, there was a tendency to increase according to the litter reuse in all broiler houses.

The C/N ratio calculated by the mass gaps of C and N observed between the beginning and end of the process was 25:1, suggesting that for every 1 kg of N lost, 25 kg of C were lost.

The phosphorus, used to verify the accuracy of the mass balance, presented an average error of 9.5%, indicating that the error for the balance, considering that measurement of element content in litter mass, animal weight, feed consumption, were satisfactory. For animal production systems, Paillat et al., (2004) considered an acceptable error of up to 20%.

In the figure 3.2 and 3.3, are showed the graphics for the distribution of N and C inlets and outputs between litter, animals and gaseous emissions. It can be noticed that for the output variables, the greatest variations between the batches are in the fractions of N in the form of N₂ and NH₃. It is also observed that the total N retained in the carcass of the bird was quite constant in the all batches, which was expected due to the similar N consumption obtained between batches. The N content in the litter at the end of the batches was increasing in relation to the intake, confirming the calculated retention levels.

In relation to the intake, nitrogen intake in the production units through the feed and the amount of nitrogen retained in the tissues of the animals presented similar proportions over the 11 cycles evaluated. Small variations in these variables were due to small differences in relation to feed consumption, weight gain, and slaughter weight between the batches. This aspect suggests an ideal standardization of broiler management throughout the experimental period.

Figure 3.2 Input and outputs of nitrogen mass balance.

Figure 3.3 Input and output of carbon mass balance

In the figure 3.3, are showed the graphics for the distribution of C inlets and output between litter, animals and gaseous emissions. The carbon content in the litter increased as the litter was reused. It can be noticed that for the output variables, the greatest variations between the batches are in the fractions of C in the form of CO₂. It is also observed that the total C retained in the carcass of the bird was quite constant in the all batches, which was expected due to the similar c consumption obtained in the batches.

3.4. Discussion

3.4.1. Carbon balance

Carbon and nitrogen balances for broiler operation are shown in Table 3.3 and Table 3.4. The C accumulation in the broiler carcass, amounting to 25.3% of the feed C input. C retention in the litter accounted to 26.45% of the feed C. The C accumulation in the market broilers was 450 to 510, mean of 488 g C bird⁻¹.

Dong et al., (2011) found different values of 22.5% and 41.4% for C retention in litter and lost in gaseous form, respectively. The bird age as well as the weight was similar to those of this study. The carbon accumulation in marketed broilers was 544 g bird⁻¹. In this study average observed was 488 g bird⁻¹. Dong et al., (2011) observed carbon losses of 722 g bird⁻¹, about half the amount observed in this study. Differences can be attributed to the accumulation of C observed in broilers. However, broiler carcass N, P, and C was not directly measured for this study, and N and C retained in the carcasses were calculated based on previously published values.

Carbon losses were between 0.85 to 1.46 kg bird⁻¹ without emissions between batches. The higher carbon concentration per area was directly related to depth litter (R^2 0.98). DH3 had the highest concentration (Table 3.3) and the lowest loss of C.

Although there are no other studies that performed mass balance of C under similar conditions, under experimental conditions the loss of C was similar to that observed by Henn et al., (2015), 1.08 kg bird⁻¹ determining the CO₂ emissions of the production of different strains of broilers in new litter.

3.4.2. Nitrogen balance

The N accumulation in the broiler carcass was the main nitrogen output, amounting to 52.2% of the feed N, followed by the N lost in the form of gas, which was 30.9% (46.7 g bird⁻¹), and lastly, litter nitrogen output or litter accumulation, that was 17% of the feed input.

The amount of N accumulation in the marketed broilers was relatively constant among the three houses, ranging between 74 and 85 g N bird⁻¹ with an average of 79 ± 2.92 g N bird⁻¹.

Values from literature were primarily for broilers raised on new litter with most of the studies calculating the N balance only. Patterson et al., (1998) used an nitrogen mass balance approach on broilers by documenting feed, broiler carcass, and litter accumulation at several commercial broiler houses. They reported values similar for broiler carcasses, 51% of the feed nitrogen input, but litter accumulation was superior, 31%. Bobrutski et al., (2013) also evaluated the loss of N per mass balance in new litter of sawdust. Feed accounted for 99% of all the N inputs. Nitrogen broiler carcasses presented relatively consistent values and was superior, having 59% of the N intake, was retained in the broiler tissue. The secondary output was the N accumulation in the litter. The N loss varied between 7 and 13 g N bird⁻¹ at the end of the growing cycle. However, Moore et al., (2011) using the mass balance, observed that nitrogen outputs as birds marketed and litter were equivalent to 78.2 and 28.7 g N bird⁻¹, respectively. Ammonia losses during the batch were 21.6 g NH₃-N bird⁻¹. Patterson et al., (1998) reported that 18 to 40% of feed N is lost to the atmosphere mostly as NH₃-N. Patterson et al., (1999) observed that NH₃-N emissions was between 19.6 and 28.5 g N bird⁻¹. The emissions of NH₃-N presented in this study are in agreement with these values, the average loss of nitrogen in the form of ammonia was, 21.88 g N bird⁻¹. Emissions of NH₃-N and N₂O-N were 14% and 1.1% of nitrogen feed input. However, Patterson et al., (1999) attributed nitrogen losses to ammonia, disregarding losses in

other forms and we observed total nitrogen emissions of 46.7 g bird⁻¹. Emissions of NH₃-N and N₂O-N were monitored but emissions of other N compounds were not measured. The main forms of nitrogen emissions are ammonia (NH₃), nitrogen oxides (N₂O, NO_x) and nitrogen (N₂, non-polluting). The emissions result from many complex interrelated processes (HASSOUNA; EGILN 2015). The difference calculated between inputs and outputs (Considering the fraction of NH₃-N and N₂O-N measured), is assumed to be the amount of N to environment in the form of N₂ (MEDA et al., 2011).

Considering the findings of Meda et al., (2011) the average fraction of N₂ estimated through mass balance, was 50.5% of total N losses. The average NH₃-N represented 46.2%. Meda et al. (2015) observed that N₂ emissions represented from 60% to 80% of total emissions and are dominant in comparison with ammonia losses (20% - 40% of total N losses).

Mitran and Harter (2008) estimated the N emission from a complete broiler cycle by mass balance with litter reused (wood sawdust) by 5 batches. They observed 67%, 26% and 13% bird accumulation, litter, and N loss, respectively, and total N emissions was 15.3±0.5 g N bird⁻¹. These authors have reported that variations in the budget components of N between chambers (these authors utilized chambers bioclimatic simulated broiler houses) illustrate some of the strengths and difficulties of constructing N budgets for broilers. As in this and other studies, the variations in nitrogen feed intake were small with the most variable component was the nitrogen accumulation in the litter. In this study, considerable effort was made to thoroughly mix and analyze the litter before placing chicks.

In addition, day-old chicks represented less than 1% of all N and C input and were not represented in the graphs. Feed and litter was calculated to be greater than 99% of all inputs.

This profile is different from that observed in the first batch with new litter, by Borbrutzki et al., (2013) and Santana (2016), where the feed corresponded to 99% of the N input in the system.

It was observed that the N retained in the tissues of the chickens was 78.9 g N bird⁻¹, which was lower than that found in other studies, such as in Santana (2016) (106 g N bird⁻¹). This can be explained by the difference in slaughter weight as well as by the retention coefficient used by this author, 65% of live weight at slaughter.

The Figure 3.2 also illustrates the accumulation of N in the litter at each reuse batch. The levels of N accumulated in the litter were different from those observed by Santana (2016), who observed a variation of 38 to 22 g N bird⁻¹ between the 1st and 4th cycles. This corresponds, respectively, to 69.8, 45.7, 41.2, and 38.3% of the N excreted in litter, and 24.4, 15.9, 14.4, and 13.4% of N input. A per-batch accumulation ranging from 10 to 37 g bird⁻¹ was observed, which is about 8 to 24% of the feed N. This difference may indicate that multiple litter reuses over a period of more than one year results in lower N accumulation/retention capacity compared to newer litter.

Santana (2016) observed greater loss of N in the last batch of litter reuse, however this behavior did not present an increase profile in all batches. Lower emissions were recorded in the third batch and the author attributed the difference in the relative humidity. Coufal et al., (2006) have already confirmed the effect of climatic conditions on litter conditions, however, this effect refers more to the season than to relative humidity, specifically. In this study, a tendency of increase N losses between 11 to 17 batches was not observed. However, it was observed that the variations can be attributed more easily to the management adopted by the producer and other factors already described in other studies.

In addition, intensive litter reuse can result in changes in the fractions of lost N, as was observed in the current study, but it should be confirmed with more studies. It is also possible that the losses of N will present some stability for a certain time of litter reuse. There difference/default observed in this study is higher than that observed in the studies with new litter previously mentioned, however, when considering only the losses in the form of NH₃, it

is perceived that this value is close to that observed by other authors in litter reuse after one year or fewer batches (LIN et al., 2012; MOORE et al., 2011). The difference found between the observed $\text{NH}_3\text{-N}$ and $\text{N}_2\text{O-N}$ emissions and the total loss of N was attributed to the losses in the form of N_2 . Some other authors, including Santana (2016), attribute the losses in the form of N_2 to be the difference between the balance sheet default and the fraction observed in the form of NH_3 e N_2O , however, this author did not verify balance accuracy by other stable elements such as phosphorus, and the mass litter was estimated in batches intermediates. Other studies make the mistake of disregarding losses in the form of N_2 and assign the default of N only the emissions of NH_3 (BORBRUTZKI et al., 2013).

For Santana (2016), the increase in NH_3 emissions is adequately related with amount of N consumed and excreted by birds, in addition to litter reuse. The effect of the age of the animals and their effect on the production of NH_3 already was observed by different authors (ELWINGER; SVENSSON, 1996; REDWINE et al., 2002; LIU et al., 2006; MITRAN et al., 2008). However, the effect of litter reuse on N losses has not yet been fully elucidated (COUFAL et al., 2006, MILES et al., 2014).

Only Coufal et al., (2006) used the mass balance in reused litter with 18 consecutive batches over three years in rice hulls to estimate the losses of N in the broilers houses. The authors determined nitrogen partitioning as a percentage of input averaged from 18 batches as 15.2, 56.4, and 21% for litter, broiler carcasses, and nitrogen loss, respectively. Nitrogen loss per batch varied from 4.1 g to 19.7 g per kg of marketed broiler or 7.9 to 36.5% of N inputs. These results reinforce the average loss found in the current study (34.6%). In addition, they observed significant differences in N per bird loss between the batches studied, however, these differences are strongly linked to the winter and summer periods. Nitrogen loss was greater ($p < 0.05$) for batches reared in summer vs. winter, when retention in the litter materials was lower in summer ($p < 0.05$).

To adequately compare the results of Coufal et al., (2006) and this study, only the losses of batches carried out in the summer, were considered. In this condition, the loss of N was 16.3 g kg^{-1} bird marketed, while in the current study, it was 16.8 g kg^{-1} bird marketed.

Coufal et al., (2006) also showed the loss of N in relation to the quantity excreted, considering the batches under the same conditions in this study, the average found was 70.9%, while 65% was observed in this experiment. These small differences in the fractions of lost N can still be attributed to the height of the litter, which in this study was superior (10 to 30 cm) to other studies that normally vary between 5 and 10 cm.

The observed results by Coufal et al., (2006) indicate that older litter will retain less N than newer litter in warmer weather and may have more N retention ability than newer litter in cooler weather. Comparing the results found by Coufal et al., (2006) for the batches 6,7, 8, 13, 14, and 15 conducted in the summer, losses of N per kg of bird marketed did not differ significantly ($p < 0.05$), indicating absence of litter reuse effect over the N losses.

Observed differences between the current study and other studies previously discussed are difficult to explain but may be related to litter material, litter C:N ratios, and microbial activity. In this study, lower C:N initial combined with high temperature, abundance of microorganisms, and amount of litter can have potentialized microbial activity in the litter compared with batches reared on newer litter and climatic differences.

In addition, according to Mitran et al., (2008), the losses of NH_3 can vary widely in broiler houses, since several factors affect the volatilization of NH_3 (protein content and protein profile in feed, temperature and ventilation, type of installation, season of the year, as well as the measurement method used in each specific situation), moreover, the uncertainty associated with each balance sheet should be considered. Li et al., (2009) evaluated the uncertainty of mass balance to estimate N losses compared to a method of direct measurement of NH_3

emissions in turkey production. The results revealed a discrepancy between the balance sheet and the determined emissions. The low reality of mass balance observed by author, may be due to sampling and lack good track of feed weights, mainly because the production data were obtained from the database of the integrating company, not having been obtained by the authors during the experiment. In addition, when comparing the default N of the balance, they assumed that the losses would occur only in the form of NH_3 , disregarding the fractions of N_2 and N_2O for example, and the method used to determine NH_3 emissions can also be questioned. Moreover, the balance has not been validated by a stable element.

3.5. Conclusions

During the period of each cycle and according to the total input of N and C, total losses of gaseous emissions ranged from 35 to 66 g bird⁻¹ for nitrogen and 0.84 to 1.45 kg bird⁻¹ for carbon. Average losses was 1.16 ± 0.18 kg bird⁻¹ and 46.76 ± 9.05 g bird⁻¹ for carbon and nitrogen. The litter reuse seems to increase the total loss of nitrogen and carbon. The observed nitrogen losses were three times higher than that observed in other studies.

The observed error for phosphorus was 9.5 %, indicating that the balance is a good alternative to identify the losses of nitrogen and carbon in the production of broilers.

References

- ASSOCIAÇÃO BRASILEIRA DE PROTEÍNA ANIMAL - ABPA. **Relatório anual 2015**. Disponível em: <www.abpa-br.com.br/>. Acesso em: 25 jan. 2016.
- BOBRUTZKI, K.; AMMON, C.; BERG, W.; FIEDLER, M. Quantification of nitrogen balance components in a commercial broiler barn. **Czech Journal of Animal Science**, Prague, v. 58, p. 566-577, 2013.
- COUFAL, C. D.; CHAVEZ, C.; NIEMAYER, P. R.; CAREY, P. Nitrogen emissions from broilers measured by mass balance over eighteen consecutive flocks. **Poultry Science**, Oxford, v. 85, p. 384-391, 2006.
- DONG, H.; ZHOU, Z.; ZHU, Z.; CHEN, Y.; Carbon and nitrogen budget of commercial cage-grown broilers. In: ASABE ANNUAL INTERNATIONAL MEETING, 2011, Louisville. **Proceedings...** St. Joseph: ASABE, 2011.
- ELWINGER, K.; SVENSSON, L. Effect of dietary protein content, litter and drinker type on ammonia emission from broiler houses. **Journal of Agricultural Engineering Research**, Amsterdam, v. 64, p. 197-208, 1996.
- ERISMAN, J. W.; SUTTON, M. A.; DENTENER, F.; MÖLLER, D. Ammonia in the environment: From ancient times to the present. **Environmental Pollution**, London, v. 156, p. 583-604, 2008.
- FAO. **The state of food and agriculture: food systems for better nutrition**. Rome, 2006.
- H. XIN; H. LI; R.T. BURNS; R.S. GATES; D.G. OVERHULTS; J.W. EARNEST. Use of CO_2 concentration difference or CO_2 balance to assess ventilation rate of broiler houses. **ASABE**, v. 52, n.4, p. 1353-1361, 2009.
- HASSOUNA, M.; EGLIN T. Mesurer les émissions gazeuses en élevage : gaz à effet de serre, ammoniac et oxydes d'azote. **INRA-ADEME**, Paris, ISBN: 2-7380-1375-9, 314p., 2015.
- HENN, J. D.; BOCKOR, L.; MARX, F. R.; COLDEBELLA, A.; RIBEIRO, A. M. L.; KESSLER, A. M. Emissão de dióxido de carbono pela cama de primeiro lote de frangos de corte/emission of carbon dioxide in litter in the first flock of broilers. **Revista Brasileira de Agropecuária Sustentável**, Viçosa, v. 4, p. 45-52, 2014.

- ITAVI. **Estimation des rejets d'azote, phosphore, potassium, calcium, cuivre et zinc par les élevages avicoles**. - mise à jour des references corpen-voilailles de 2006. ITAVI, Paris p.63. 2013.
- KRATZ S.; HALLE I.; ROGASIK J.; SCHNUG E. Nutrient balances as indicators for sustainability of broiler production systems. **British Poultry Science**, Edinburgh v. 45, p. 149–157, 2004.
- LIN, X. J.; CORTUS, E. L.; ZHANG, R.; JIANG, S.; HEBER, A. J. Air emissions from broiler houses in California. **Transactions of the ASABE**, St. Joseph, v. 55, p. 1895-1908, 2012.
- LIU, Z.; WANG, L.; BEASLEY, D.B. A review of emission models of ammonia released from broiler houses. **ASABE**, St. Joseph, p.123-132, 2006.
- MEDA, B.; HASSOUNA, M.; AUBERT, C.; ROBIN, P.; DOURMAD, J. Y. Influence of rearing conditions and manure management practices on ammonia and greenhouse gas emissions from poultry houses. **World's Poultry Science Association**, Cambridge, v. 67, p. 441-456, 2011.
- MILES, D. M.; MOORE, P. A.; BURNS, R. T.; BROOKS, J. P. Ammonia and nitrous oxide emissions from a commercial broiler house. **Journal Environ Quality**, Madison, v.43, p.1119-24, 2014.
- MITRAN, L.; HARTER- nitrogen emissions from commercial broilers grown in environmental chambers. **Journal of Poultry Science**, Campinas, v. 17, p.34-46, 2008.
- MOORE, P. A.; MILES, D.; BURNS, R.; POTE, D.; BERG, K.; CHOI, I. H. Ammonia emission factors from broiler litter in barns, in storage, and after land application. **Journal of environmental quality**, Madison, v.40, p.1395-1404, 2011.
- OSORIO, J. A.; TINOCO, F. F.; CIRO, H. J. Ammonia: a review about concentration and emission models in livestock structures. **Dyna**, Medellín, v. 76, p. 8999, 2009.
- PAILLAT, J.-M.; ROBIN P.; HASSOUNA, M. Bilan environnemental du procédé de compostage de lisier de porc sur paille suivant la méthode Guérévez. **INRA**, Paris, 39 p, 2004.
- PATTERSON, P. H.; LORENZ, E. S.; WEAVER, W. D. Litter production and nutrients from commercial broiler chickens. **Journal of Applied Poultry Research**, Athens, GA, v. 7, p. 247–252, 1998.
- REDWINE, J. S.; LACEY, R.; MUKHTAR, S.; CAREY, J. B. Concentration and emissions of ammonia and particular matter in tunnel-ventilated broiler barns under summer conditions in Texas. **Transactions of the ASABE**, St. Joseph, v. 45, p. 1101–1109, 2002.
- SANTANA, I. K. S. DA. **Emissões de gases de efeito estufa e amônia oriundas da criação de frangos de corte em múltiplos reúsos da cama**. 2016. 130p. Tese (Doutorado em Energia nuclear na agricultura) - Universidade de São Paulo, Piracicaba, 2016.

4. EMISSIONS OF AMMONIA AND GREENHOUSE GASES OF BROILER HOUSE IN SOUTHERN BRAZIL

ABSTRACT

As the production of broilers has increased and become more concentrated in the last decades, concern about environmental aspects and the emission of gases has also increased. Thus, robust scientific data are needed to accurately estimate atmospheric emissions from broiler operations. Three dark house systems, integrated in the agro-industry, located in the south of Brazil, were evaluated to identify the emission rate of NH_3 , and GHG (N_2O , CO_2 and CH_4) under conditions of litter reuse. Also, the most important variables that influenced the ammonia and carbon dioxide flux were identified. The data collection range was 3 and 4 batches in each house, with an average duration of 41 days and 2.8 kg of body weight, between October 2014 and May 2015. Litter had been reused by 10 batches before the start of this study. Air sampling was carried out on weekly basis in the morning and afternoon period using bags, known as "Tedlar®", (SKC®) connected to a pump. They were analyzed by the photoacoustic gas analyzer (INNOVA 1412). Temperature, relative humidity, and air velocity were also monitored. The method of concentration ratio was used to determine the emissions, and the validation occurred by the water balance. Mass balances for C and H_2O were determined. Emission fluxes for NH_3 and CO_2 were determined using the air velocity data obtained during the air samplings. Average emission rates obtained by method of concentration ratio were 0.63 ± 0.1 ; 100.2 ± 16 ; 0.23 ± 0.15 and 0.06 ± 0.02 g bird⁻¹ d⁻¹ for NH_3 , CO_2 , CH_4 and N_2O , respectively. The emissions of NH_3 have been influenced by the bird weight, ventilation rate, and N concentration. For the CO_2 , the emission have been influenced by the ventilation rate, outside temperature, and bird weight. Ventilation seems to be an important descriptor of CO_2 and NH_3 emissions

Keywords: Concentration ratio; Mass balance; Emission rate

4.1. Introduction

Gas emissions and air quality are important environmental topics for poultry production. The importance of air quality from animal feeding operations has been well recognized in Brazil, especially, which is among the largest suppliers of animal products. Emissions estimates are needed, particularly in countries that cosigned the Kyoto protocol, for the broiler industry's impact to be assessed on local and regional air quality.

One of the major environmental concerns in the poultry industry is NH_3 volatilization (MOORE, 1998), but, besides ammonia, this production system can also emit greenhouse gases (GHGs). Since poultry are monogastric, due to its digestive physiology, it produces only slightly amounts of CH_4 . However, methane can be emitted from litter reactions inside the building, manure storage, and during manure application by fermentation of organic matter (CALVET et al., 2011; BROUCEK; ČERMAK, 2015). N_2O production from poultry manure can be emitted during nitrification and denitrification. According Xin et al., (2011) this reactions and nitrate reduction can occur in some litter systems. Moreover, feces composition and enzymes involved, in addition to conditions after excretion can be influence N_2O formation (XIN et al., 2013). The main source of carbon dioxide is animal respiration and decomposition of organic matter (KNÍŽATOVÁ et al., 2010a). Gas production and emission in poultry or any animal facilities involve complex processes, and several variables may influence the emissions (CALVET et al., 2011; BROUCEK; ČERMAK, 2015).

Litter type, litter management, humidity, temperature (CALVET et al., 2011; REDDING, 2013), season of the year (CASEY et al., 2003; MIHINA et al., 2010), ventilation rate (KNÍŽATOVÁ et al., 2010b; WALKER et al., 2014), ventilation system, birds diet, and age (PESCATORE et al., 2005; GATES et al., 2008; HARPER et al., 2010; LIN et al. 2012) already have been reported in the literature as variables affecting emissions.

For Meda et al. (2015) the effect of other factors can be expected, such as litter amount, initial amount, flocking density, mortality, temperature and moisture of outside, but little is known about these variables.

Scientific knowledge of GHG, and NH₃ emissions in the broiler production of Brazilian systems is still limited. Some emissions data were presented by Lima et al., (2011); Miragliotta et al., (2004); Menegali et al., (2012); Carvalho et al., (2011) and more recently Henn et al., (2015) presented models to estimate CO₂ emissions produced by two strains of broiler chickens. Lima et al., (2015) developed a model to estimate ammonia emissions considering variables such as acidity, litter temperature, and age of the animals. In Brazil, however, emission inventories have largely relied on emissions rates that do not represent all current production conditions.

Broiler houses in Brazil are similar, but there are management differences among regions, including batch density, litter management, building dimensions, and ventilation systems. These differences may affect the environmental conditions, moisture, ammonia content, and heterogeneity of litter, thereby changing the GHGs emissions rate (LIMA et al., 2015). The litter conditions are suggested to be correlated with emissions (GROOT KOERKAMP et al., 1998, WHEELER et al., 2006).

Moreover, the reuse of the litter between two and three years is a common practice in production systems located in the southern region. This is an interesting alternative for producers because it reduces the production cost and amount of waste generated.

The litter reuse is considered a factor that increases ammonia emissions. Although Wheeler et al., (2006) did not show clear increase in ammonia emission with reuse of the litter, but this was due to seasonal variation. Miles et al., (2014) evaluated emission rates for ammonia and N₂O in Mississippi within the extent of litter reuse and was unable to show increase emissions factors, like other studies in which litter had used during a single year or less. Calvet et al., (2011) found that broiler litter accounted for 20% of the total CO₂ produced from broiler facilities, but the data on the intensive litter reuse yet are scarce, and, thus, to represent diverse broiler production systems and climates, more research is needed.

Management of the production batches adopted is an important factor in emissions of gases because it falls on the quality of the litter and environmental conditions for the animals. Meda et al., (2015) conducted an extensive bibliographic review to identify well-known aspects that affect emissions and concluded that they can be separated into two types: creation of practices for management of animals and practices for management of litter.

While many of these factors are already known, there is a lack of information on some important factors, making the interpretation and comparison of published data complicated. When the result of a measurement is reported, the quality of that result should also be reported to provide an idea of its reliability (WOOD et al., 2015).

Wood et al., (2015) discussed quality criteria used to studies for emission rate (ER) estimation, but they did not discuss descriptors that should be used to define farm categories more or less accurately.

To understand the variables that have strong influence on emissions allows one not only to know the impact of regional air quality, but also to identify practical management that can minimize emissions or improve result quality.

This study focused on dark houses. Therefore, it was also important to identify descriptors that influence the variability of emissions in dark houses.

The primary objective of the current study was to determine emissions rate of NH_3 , and GHG from three commercial broiler houses (dark houses) in southern Brazil for reused litter and different management practices. A secondary objective was to report which are the variables that most important to describe the emissions, creation of practices for management of animals, or practices for management of litter.

4.2. Materials and Methods

4.2.1. Broiler houses

The experiment was conducted in three commercial broiler farms located in southern Brazil (State of Santa Catarina) between October 2014 and May 2015. Three dark house (DH) systems (Table 4.1) had forced ventilation, nine exhaust fans, evaporative cooling, and the lateral areas were closed off with double black polypropylene curtains.

The chicks used from day 0 to 14 of the grow-out period had 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 20 lx for the first weeks of grow-out (7-21 d), and it was set at 3 lx for the remainder of the grow-out cycle (41 d), using automatic light control based sensors set in the houses. The three dark houses had similar ventilation systems with the air inlet at one end, and the outlet at the opposite side. Ambient air temperature was controlled automatically using the association of the evaporative cooling system and negative pressure ventilation. decrease Air temperature was programmed to decrease from 32 °C to 27 °C during the first two weeks and then finally to 22 °C during the last week of the grow-out phase.

Houses had three automatic feeder lines that stretched the length of the house and four automatic nipple water lines. The adopted average batch density was approximately 14 birds m^{-2} , which is considered ideal according to the Broiler Manual of this lineage. The brooding dimensions were 12 x 25m and were in the center of the house.

Table 4.1 Dates of each broiler house, temperature, ventilation rate and growth period in each batch.

Rearing System	DH1			DH2			DH3		
Batches	1	2	3	1	2	3	1	2	3
Birds used	20928	20125	20946	16883	16894	16897	12717	13445	12459
growth period (days)	41	43	40	39	40	41	40	40	40
surface house m ²	1500	1500	1500	1200	1200	1200	960	960	960
outside temp °C	21 ± 4.5	22.6 ± 3.7	22.4 ± 4.1	22.6 ± 5.2	23.9 ± 4.5	23.8 ± 4.5	23.1 ± 3.1	23.2 ± 3.5	21.2 ± 3.85
In-house temp °C	26.1 ± 2.2	27.3 ± 3.3	27.3 ± 2.5	27.4 ± 2.7	29.5 ± 2.7	29.4 ± 3.1	26.1 ± 3.2	28.6 ± 3.2	26.7 ± 1.6
ventilation rate m ³ min ⁻¹	2023 ± 1685	4748 ± 2514	4607 ± 3125	2985 ± 1748	3718 ± 2431	3400 ± 1729	2496 ± 1545	2853 ± 873	1642 ± 1199
Max ventilation rate m ³ min ⁻¹	4952	6609	9210	6100	6029	5587	3952	4085	3650
Min ventilation rate m ³ min ⁻¹	875	322	1789	2058	673	1271	705	1723	476

4.2.2. Animals

The birds used during the experimentation were males Cobb 500 and Ross. Birds were grown to approximately 2.8 kg with an average growth period of 41 days. The average mortality factor was 4%.

4.2.3. Litter conditions

In both houses, broilers were reared with reused litter. Pine wood shavings were the original bedding material set on the house floor, and the litter had been reused from batches 11 to 17 for this research. After slaughter of the broilers, the cake or upper compacted layer of litter was removed and the application of calcium oxide (CaO) was performed between batches. The interval regular between batches was 6 to 10 days with opening of the curtains for ventilation in DH1, DH2, and DH3 while the house remained closed. One day before the animals input, the brooding chamber was prepared in the center of housing with the addition of 2-cm of wood shavings. When the birds reached between 14 days to 30 days, the litter was mixed daily.

Every week and near the end of each batch, litter samples (approximately 1 kg) were collected. Samples were analyzed for moisture, pH, and nutrient content (nitrogen, carbon and phosphorus). Samples collected before the first batch were subjected to the same analyses. Moisture was determined by loss in weight after drying bedding samples for 48 h at 65 °C, and pH was measured by standard methodology (APHA, 1998). Carbon and nitrogen nutrients total were determined via combustion analysis (NELSON; SOMMERS, 1982), in elemental analyzer of C and N.

4.2.4. Measurements of temperature and air velocity

Indoor and outdoor temperature and relative humidity were continuously recorded during the whole period with temperature and humidity sensor (type TESTO 174H). The ventilation rate was monitored weekly with a hot wire anemometer (TESTO 435). Measurements of the air velocities were taken in the installation in the absence of the animals under the different combinations of exhaust fans used for each temperature range. These measurements were compared with the ventilation values obtained at the time of air samplings. There was a difference of more than 5% for batch 4 in DH3 between the air velocity measurements performed in the absence of the animals and during the cycle. Thus, the flow data of this batch were disregarded for the determination of the emission rate.

Measurements were performed at three positions in the broiler house. The cooling pad is the first sampling point, the middle position was the lengthwise midpoint of the house, and the final position was located 30 m away from the middle toward the exhaust fans at the end of the house (figure 3.5).

Figure 3.4 Schematic plan view of the dark house with point measurement for air temperature and air velocity used in the study.

4.2.5. Gas concentrations

Concentrations of gases NH_3 , CO_2 , CH_4 , and N_2O were measured weekly after sampling in bags (6-day sampling in each batch). Outdoor air sampling was also carried out simultaneously. Air samples were collected with sampling bags made of polymeric materials connected to a pump. The duration of sampling in each house was 30 minutes. In the period when the birds were in brooding chamber the data were recorded only in the area occupied by the birds.

The gas concentrations in the bags were measured using a photoacoustic multigas analyzer (Innova 1412).

4.2.6. Gas emission determination

4.2.6.1. Flux emission

The emission fluxes were determined using calculated air flow from the average of 360 speed measurements, performed as described in item 4.2.4, during every air sampling.

The equation proposed by Robin et al., (2006) was used to determine the fluxes.

$$E = Q \times \rho_i \times (C_o - C_i) \quad (1)$$

Where: E is emission rate (mg h^{-1}) of a particular gas ($\text{CO}_2\text{-C}$, $\text{NH}_3\text{-N}$); Q is the air flow ($\text{m}^3 \text{h}^{-1}$); C_o and C_i were the outlet and inlet concentrations (mg m^{-3}); and ρ_i conversion of the volume of air flow passing through the installation in $\text{m}^3 \text{h}^{-1}$ for mass flow in kilograms of dry air per hour, which allows to apply the laws of conservation of mass and energy.

The weekly emission flux was used to identify the variables that best describe the emissions flux of NH_3 and CO_2 .

4.2.6.2. Method of Concentration ratios

The concentration ratio method of Paillat et al., (2005), developed initially to quantify gaseous emissions from compost heaps and adapted by Ponchant et al., (2008), was used to quantify gaseous emissions from broiler house.

The simplified method was based on the concentration ratios method. The following equations (equations 1 to 6) have been used:

$$C_{losses} = E_{CO_2-C} + E_{CH_4-C} \quad (1)$$

Where: E_{CO_2-C} and E_{CH_4-C} are C emissions in CO_2 and CH_4 forms, respectively.

Assuming because of convective transfer:

$$\frac{E_{CH_4-C}}{E_{CO_2-C}} = \left[\frac{G_{CH_4-C}}{G_{CO_2-C}} \right] mean \quad (2)$$

Where: G_{CO_2-C} and G_{CH_4-C} are gradients of C concentrations in CO_2 and CH_4 forms, respectively.

Based on these equations, the emissions were expressed for each gas produced in the house:

$$E_{CO_2-C} = \frac{C_{losses}}{\left[1 + \left(\frac{G_{CH_4-C}}{G_{CO_2-C}} \right) mean \right]} \quad (3)$$

$$E_{CH_4-C} = E_{CO_2-C} \times \left(\frac{G_{CH_4-C}}{G_{CO_2-C}} \right) mean \quad (4)$$

For other gases:

$$E_{NH_3-N} = E_{CO_2-C} \times \left(\frac{G_{NH_3-N}}{G_{CO_2-C}} \right) mean \quad (5)$$

$$E_{N_2O} = E_{CO_2-C} \times \left(\frac{G_{N_2O-N}}{G_{CO_2-C}} \right) mean \quad (6)$$

Where: E_{NH_3-N} and E_{N_2O-N} are N emissions in NH_3 and N_2O forms, and G_{N_2O-N} and G_{NH_3-N} are gradients of N concentrations in N_2O and NH_3 forms, respectively.

In fact, $\left(\frac{G_{CH_4-C}}{G_{CO_2-C}} \right)$ depend on the days of measurements. Ponchant et al., (2008) suggested observing

during 5 and 9 week for turkey. Duration of batches was 6 weeks in this case. To have a rough estimate of emissions

uncertainty, average and standard deviation was calculated for $\left(\frac{G_{CH_4-C}}{G_{CO_2-C}}\right)_{mean}$ using 2 to 6 weeks. Week 1 was discarded to avoid underestimation (small ventilation and small gradient). Therefore, a small gap can appear between C_{losses} and $E_{CO_2-C} + E_{CH_4-C}$ in the presented results.

The fraction of CO_2 emitted from litter as estimated, assuming that animal respiration was 43.3% of C intake (Henn et al., 2015).

4.2.6.3. Validation of the concentration ratio method

The method was validated as proposed by Ponchant et al., (2008) and Robin et al., (2006) using the water balance default and the losses in the form of water vapor observed by the concentration ratio method.

4.2.7. Batch Emission Rate (ER)

Emission rate of this study were determined from the average emission of each gas (ammonia, carbon dioxide, methane, and nitrous oxide) for the average of all batches, average duration of the batches (41 days), number of birds, and average live weight (lw) at slaughter according to data presented above. The data is presented in $g\ bird^{-1}d^{-1}$ and $g\ kg^{-1}\ lw\ d^{-1}$ to ease comparison and increase accuracy between comparison. Parameters such as stocking density, market weight, age, litter condition, and downtime between batches were considered.

4.2.8. Annual Emission Rate (AER)

To extend the calculation to the annual emission rate, average ER by bird and by house was used, multiplying by the appropriate number of batches in year. The annual emissions rates were calculated using the values obtained by the concentration-ratio method.

For the annual calculation, age of birds of 41d, market weights of 2.8 kg with 6.5 batches per house grown annually was assumed, which resembles Southern Brazil broiler production data. An annual emission rate for each house and batch was calculated, and the average of these values for NH_3 , CH_4 , and N_2O is presented.

4.2.9. NH_3 and CO_2 emissions descriptors

In order to identify the variables that best describe the NH_3 and CO_2 emissions of this study, they were tested in mixed linear models. These factors include the effect of environmental variables (inside and outside temperature, inside and outside air humidity, and inside enthalpy), litter (moisture, litter nitrogen and carbon), management (batches and installation), and zootechnical performance of the animals (weight and age), totaling 15 variables. The effect of litter pH was not tested because pH was alkaline during all the batches. To select the variables tested in this study, an bibliographical review was carried out to identify the main aspects that can affect the emissions.

4.2.10. Statistics

The weekly data were analyzed using the PROC MIXED of the Statistical Analysis System © (SAS, Inst.Inc., Cary, NC, USA) (SAS, 2012), using the mixed model theory with consideration for the 110 measures of emissions flux, having up to six parameters and different combinations of variables with fixed and variable effects. The structure of the matrices used was chosen based on the lower value of the Akaike Information Criterion (AIC) and significance of all matrix variables. The estimation method used was the Maximum Likelihood Method. The analysis was performed using the T test, whenever the F test was significant at 5% ($P \leq 0.05$).

4.3. Results

4.3.1. Litter properties

The results obtained for litter properties showed that some variables have small changes during the production cycle. The litter acidity did not show great variation during the production cycles, so it seems that litter reused for a long period seem to maintain alkaline pH throughout the production cycle with more pronounced variations only in the areas of broiler house where the brooding was installed, since addition of new litter occurs in this area when starting the batch. pH ranged from 8 to 8.9 during the production cycle in all batches and broiler house. This alkalinity can be explained by the fact that initially in new or lightly reused litter, the initial pine wood shavings component presents less accumulation of excreta and, consequently, less microbial activity, resulting in litter with more acidic pH. As excreta accumulation occurs, the microbial activity is accelerated causing the hydrolysis of uric acid and raising the pH of litter (WHEELER et al., 2006).

The nitrogen and total carbon content increased by about 1 g kg⁻¹ of dry matter between the beginning and end of the production cycle in most batches.

The average litter moisture at the beginning of the production cycle was around 24%, and at the end of the cycle, it was on average 32%. The litter moisture observed in this study was similar to that observed by other authors (MILES et al., 2006; MILES et al., 2008). The period had high average daily values for temperature, and this may have favored the evaporation of the water from litter in some moments. According to Sneath et al., (1997), very dry broiler litter inhibits microbial processes, which reduces GHG and NH₃ emissions. Also in relation to litter moisture, a reduction in this variable was observed between the end and next beginning of each litter reuse. This behavior can be explained by the sanitary emptying period of 6 to 10 days. The C:N ratio was always less than 20 in all batches.

4.3.2. NH₃ and CO₂ flux emission

The emission fluxes of NH₃-N and CO₂-C are presented in the tables 4.2 and 4.3. In this tables (4.2 and 4.3) the emission fluxes were expressed in proportions of C and N (CO₂-C and NH₃-N), conversions being carried out on the basis of molecular weights.

CO₂-C flux showed a similar behavior in all the facilities, presenting an increase according to the age of the animals. Flow started between 300 ± 66 and 582 ± 169 mg bird⁻¹ h⁻¹ and increased to about 1550 ± 279 and 1991 ± 276 mg bird⁻¹ h⁻¹.

Table 4.2 Carbon dioxide emissions flux observed in the weeks. The emission fluxes were expressed in proportions of carbon.

Weeks	Flux CO ₂ -C (mg bird ⁻¹ h ⁻¹)		
	DH1	DH2	DH3
1	582 ± 169	300 ± 66	394 ± 124
2	816 ± 229	596 ± 83	370 ± 89
3	850 ± 233	922 ± 192	572 ± 68
4	1255 ± 131	1283 ± 48	1075 ± 238
5	1661 ± 116	1512 ± 251	1502 ± 237
6	1991 ± 276	1888 ± 185	1550 ± 279

NH₃-N flux began around 3.2 ± 0.7 and 6.1 ± 1.5 mg bird⁻¹ h⁻¹ between the facilities in the first week increased with the age of the animals reaching the maximum values observed in the fifth and sixth week in DH1 and DH3. DH2 presented a different behavior. The average flow was 21.49 mg bird⁻¹ h⁻¹ considering all facilities.

Table 4.3 Ammonia emissions flux observed in the weeks. The emission fluxes were expressed in proportions of nitrogen.

Weeks	Flux NH ₃ -N (mg bird ⁻¹ h ⁻¹)		
	DH1	DH2	DH3
1	3.2 ± 0.7	5.3 ± 1.7	6.1 ± 1.5
2	4 ± 0.7	8.7 ± 3.1	6.7 ± 1.1
3	20.2 ± 5.9	31.7 ± 8.3	11.2 ± 0.8
4	28.8 ± 4.3	37.3 ± 2.6	21.4 ± 5
5	37.9 ± 4.9	35.6 ± 9.6	35 ± 6.5
6	38.3 ± 7.3	26.7 ± 3.1	33.2 ± 9

Through the results it is possible to observe that there is an effect of the age in weeks on the emissions. This result was also evidenced when identifying the variables that describe the emission fluxes.

4.3.3. Gas emissions rate

NH₃ emission rate ranged from 0.34 to 0.85 g NH₃ bird⁻¹ d⁻¹ between batches, and the average between 10 batches was 0.63 g NH₃ bird⁻¹ d⁻¹.

When expressed as percentage N excretion, NH₃-N emission rates varied between house. Values for NH₃-N emission represented between 16 and 39%, and the average was 28% of N excretion.

The largest losses of NH_3 were in batch 3 in house DH3, batch 4 in DH1. It was different for the losses of CO_2 , which were higher in batch 4 in house DH1 and batch 3 in DH2. There was a correlation between the number the reuses litter and the NH_3 emission rates per bird in DH3 (0.99).

The variability observed in the NH_3 emission rate also occurred in the CO_2 emissions rate. Variability in NH_3 emissions is showed by ratio between NH_3 emission and CO_2 emission (CO_2/NH_3) in Table 4.2. The higher relationships of CO_2/NH_3 occurred when lower NH_3 losses were observed. That is to say that when NH_3 emissions rate was lower, the ratio was high.

The house that observed the lowest average NH_3 emissions rate was DH1. The house that had observed lowest average CO_2 emissions factor was DH2. The CO_2 emission rate (respiration + litter emissions) between batches varied of 73 to 128 $\text{g bird}^{-1} \text{ d}^{-1}$, the average was 100,2 $\text{g bird}^{-1} \text{ d}^{-1}$ and the CO_2 losses by bird was between 2.9 kg bird^{-1} to 5.2 kg bird^{-1} .

The highest CH_4 emissions rate was in DH1. The emissions vary of 0.05 to 0.49 $\text{g bird}^{-1} \text{ d}^{-1}$ between all batches, and the average was 0.23 $\text{g bird}^{-1} \text{ d}^{-1}$.

Daily N_2O emissions vary between 0.03 and 0.08 $\text{g bird}^{-1} \text{ d}^{-1}$. The N_2O emissions in nitrogen form corresponded to 1.8 ± 0.4 % of N excreted.

For three measurement periods (batches) at each broiler house, the water balance (reference), and emission estimates by the concentration ratio method were calculated (Table 4.5).

For each batch, the concentration relations method presented results very close to the default observed in the mass balance. The measurement error for this method was less than 10%. The observed difference between the water balance and the emissions estimated by the concentration ratio method varied between 2 and 5.9%. These values are close to the differences observed by Ponchant et al., (2008) in summer in the production of turkeys. The results obtained allow us to validate the estimations of emission obtained by the concentration ratio method.

Table 4.4 Emissions rates of greenhouse gases by bird.

Rearing System	DH1				DH2			DH3			
Batches	1	2	3	4	1	2	3	1	2	3	Average
Emission rate g d ⁻¹ bird ⁻¹											
NH ₃	0.61	0.34	0.56	0.81	0.79	0.56	0.76	0.45	0.55	0.85	0.63±0.16
N ₂ O	0.03	0.07	0.05	0.10	0.08	0.07	0.05	0.04	0.05	0.05	0.06±0.02
CO ₂	97.55	96.9	108.16	128.57	73.86	75.86	109.55	102.86	102.94	106.58	100.26±16
CH ₄	0.34	0.32	0.36	0.01	0.33	0.49	0.05	0.19	0.12	0.12	0.23±0.15
CO ₂ /NH ₃	159.9	285	193.1	158.7	93.4	135.4	144.1	228.5	187.1	125.3	158.7

Table 4.5 Validation concentration ratio method by water.

	DH1				DH2			DH3		
	1	2	3	4	1	2	3	1	2	3
Mass balance - Default (kg house-1)	141123	139289	136625	138607	91929	88316	90158	70558	71789	72053
Concentration ratio (kg house-1)	136231	135456	139389	133100	87520	90789	86345	68350	67549	69341
Difference	4892	3833	-2764	5507	4409	-2473	3813	2208	4240	2712
Difference (%)	3.4	2.7	-2.0	3.9	4.7	-2.8	4.2	3.1	5.9	3.7

4.3.4. Annual emission rate

By integrating the daily emissions, the cumulative emissions are determined by production cycle, considering that over the course of a year, 6.5 production batches are produced. The sum of the accumulated emissions of each cycle produced results in the accumulated emissions per 6.5 birds housed year⁻¹, that is, determined for a period of 365 d.

The NH₃ annual emission rate was 168 ± 43 g bird-place⁻¹ yr⁻¹ and 2.3 ± 0.6 kg m⁻² yr⁻¹.

The N₂O annual emission rate was 16 ± 4 g bird-place⁻¹ yr⁻¹ and 224 ± 56 g m⁻² yr⁻¹. For CH₄, it was 61 ± 16 g bird-place⁻¹ yr⁻¹ and 854 ± 86 g m⁻² yr⁻¹.

4.3.5. Emissions descriptors

Matrices of 1 to 6 parameters were developed with different combinations of variables, totalizing 450 matrices. These matrices are presented in Appendix A, B and are ranked according to the AIC value in ascending order. The choice of the best matrices was based on the lowest AIC value and the significance of all parameters at the 5% level. The results allowed to identify the matrix with the best combination of variables that describes the emission flux of NH₃ and CO₂. The values of significance of each variable of the matrix of NH₃ and CO₂ are presented in table 4.6 and 4.7.

Table 4.6 variables for NH₃ flux and significance levels.

Effect	Pr > t
Intercept	<.0001
Weight	<.0001
Velocity	<.0089
N_litter	0.0002
N_litter*N_litter	0.0002
Weight*Weight	<.0001

Table 4.7 variables for CO₂ flux and significance levels.

Effect	Pr > t
Intercept	0.0394
Weight	0.0008
Batch	0.0058
Weight*Weight	0.0158
Velocity	<.0001
Te	0.0002

Through the results, it was possible to observe how the effect of each variable on the emission flux occurs. NH₃ flux undergoes positive influence with the weight of the animals. It was observed that the

concentrations of ammonia show significant difference between the morning and afternoon periods, but this effect does not appear to for fluxes. CO₂ flux has a positive effect based on weight, batch, and air velocity. The increase in external temperature affects emissions. The increase in the weight of the animals shows a strong relation with the increase of the emission flux, since for both models, there was a quadratic effect of this variable.

4.4. Discussion

4.4.1. Emissions rates

4.4.1.1. Gas emission rate

The average ammonia (NH₃) emission rate in this study was 0.63 g of NH₃ bird⁻¹ d⁻¹, to facilitate comparison with previous studies where the factor was also calculated for g of NH₃ kg⁻¹ lw d⁻¹ (broiler kilogram marketed). The emission rate was 0.22 g of NH₃ kg⁻¹ lw d⁻¹.

Although Brazilian broiler emission rates may not be ideally comparable to US emission rates due to different management, housing type, and climate, the results found in this study agree well with the value (0.24 g of NH₃ kg⁻¹ lw d⁻¹) reported by Miles et al., (2014) for birds of roughly the same age growing in reused litter in Mississippi.

Gates et al., (2008) reported value similar (0.30 g of NH₃ kg⁻¹ lw d⁻¹) for reused litter per 3 batches with a growth period of 43 days.

Haper et al., (2010) and Knizatova et al., (2010c) reported smaller values, but different litter material was utilized. Haper et al., (2010) utilized rice hull litter reused for 3 batches and found an emissions factor of 0.13 g of NH₃ kg⁻¹ d⁻¹. Knizatova et al., (2010c) utilized new chopped wheat straw for each batch studied.

Other values were reported by Wood et al., (2015). He presented emissions rate considering three precedent studies in North America with different methods of measurement, reused litter, and new litter and found an average emissions rate of 0.6 g of NH₃ kg⁻¹ lw d⁻¹. It is assumed that this difference can be related by duration of batch because the bird age was 49 and 52d. The density and numbers of reused litter were lower than in the current study, and the litter material was rice hulls.

In Brazil, some studies observed the emissions rates in broiler houses. Lima et al., (2015) in the state of Mato Grosso evaluated emissions using the capsule method suggested by Jeppsson (1999) and litter of wood shavings reused third time. The value reported was approximately half of the current study, being 0.28 g of NH₃ bird⁻¹ d⁻¹ or 0.14 g of NH₃ kg⁻¹ lw d⁻¹. Another previous study carried out by Mendes et al., (2014) for monitoring NH₃ emissions from a mechanically and naturally ventilated broiler house also reported value lower than that of this study. The bird stocking density was between 11.1 and 13.5 birds m⁻² and had marking age of 43 days. For mechanically ventilated houses, a value of 0.32 ± 0.10 g of NH₃ g bird⁻¹ d⁻¹ was observed. However, the study by Mendes et al., (2014) had only one breeding cycle to estimate the emission rate for NH₃ emissions. Lima et al., (2011) in São Paulo observed 0.19 g bird⁻¹ d⁻¹ for new litter in broiler house with negative pressure (Tunnel System) and density of 14 birds m⁻². Santana (2016) observed NH₃ emission of 14 g bird⁻¹ in the fourth cycle of litter reuse.

The values of emission rates obtained in the Brazilian production systems were lower than those obtained in this study. It should be noted that these studies were carried out in different regions of Brazil and there are methodological differences, thermal environment, and type of management (such as slaughter weight, litter reuse and

bedside management) between the studies. In addition, Gates et al., (2008) reported that due to the differences in the management of broiler production, it is necessary to develop methodologies to evaluate the emission of gases, through regional or national inventories, but based on the peculiarities of production in the region.

Carbon dioxide emission rates per bird varied between the houses, 2.9 kg bird⁻¹ to 5.2 kg bird⁻¹ (73 g to 128 g of CO₂ bird⁻¹ d⁻¹), and the average of all batches was 4.11 kg bird⁻¹. This result is close to the value reported by Henn et al., (2015) in Brazil, who observed that 4.09 kg of CO₂ bird⁻¹ for Cobb males created new litter.

Burns et al., (2008) observed a value of 90 g of CO₂ bird⁻¹ d⁻¹. Henn et al., (2015) also observed that the litter corresponds to 17.3% of CO₂ emissions. Calvet et al., (2011) in Spain observed values slightly lower, being 3.58 to 3.60 kg of CO₂ bird⁻¹, but the litter accounted 20% of CO₂ emissions. In the CO₂ estimated using the coefficient C expiration found by Henn et al., (2015), 43.3% of C intake, the average value reported here, was higher in comparison with the other studies mentioned above, while litter accounted 25% of CO₂ emissions. A discussion on emission rates is difficult to deepen as there are few studies that have CO₂ emission factors. In addition, this gas is not considered in global warming protocols.

For N₂O, the average emission rate of all batches in this study was 0.06 g of N₂O bird⁻¹ d⁻¹ or 0.02 g of N₂O kg⁻¹ lw d⁻¹. Although emission rate for N₂O are scarce in the literature, this results confirmed those observed by Miles et al., (2014), that was 0.08 g of N₂O bird⁻¹ d⁻¹ or 0.03 g of N₂O kg⁻¹ lw d⁻¹ in broiler houses in Mississippi.

Calvet et al., (2011) observed values lower, being 0.05 g of N₂O bird⁻¹ d⁻¹ in winter and 0.03 g of N₂O bird⁻¹ d⁻¹ in summer. Burns et al., (2008) reported values of N₂O emissions of 0.05 ± 0.08 g and N₂O kg⁻¹ lw d⁻¹ in a commercial broiler house with rice hulls litter reused per 3 and 5 batches for a duration of 52d.

The literature data present considerable variations, such as those reported by Chadwick et al., (1999), who estimated at 63.64 mg bird⁻¹ d⁻¹ of N₂O in UK broiler house (assuming an average live weight of 1.7 kg bird⁻¹).

The result for CH₄ emission rate in this study (0.23±0.15 g CH₄ bird⁻¹ d⁻¹) was higher than found by Burns et al., (2008).

The values observed by Calvet et al., (2011) in mechanically ventilated broiler farm of Spain with new litter of rice hulls also was lower. The value was 0.01 g CH₄ bird⁻¹ d⁻¹ and no information about litter moisture initial was provided.

In Brazil, Santana (2016) reported lower values of 3.6 mg of N₂O bird⁻¹ d⁻¹ and 0.01 g CH₄ bird⁻¹ d⁻¹ modeling the emissions to six litter reuse.

The IPCC (2006) proposes the emission of 0.004 g bird⁻¹ d⁻¹ of N₂O and 0.05 g bird⁻¹ d⁻¹ of CH₄ (assuming an average live weight of 1.7 kg bird⁻¹), respectively, but do not consider the litter management (reuse). However, the estimates presented in the IPCC report can be quite variable and contested by Barton et al. (2008) at scales that are not global or national because they do not consider the management practices, type of substrate, and climate of the region, which are important factors that interfere in the production of GHG and NH₃.

4.4.1.2. Annual emission rate

Comparing the annual accumulated emissions of NH₃, CH₄, and N₂O with those obtained in Brazil, a greater discrepancy between the values was observed. Due to differences in handling and shed conditions, it is difficult to compare these values. For the accumulated emissions of NH₃, Gates et al., (2008) found, on average, 198.6 g bird-place⁻¹ year⁻¹, from the monitoring of several mechanical ventilation sheds in Kentucky with reused

litter. This emission was close to the value obtained in this study and approximately double that obtained by Santana (2016) in broiler houses with natural ventilation.

The NH_3 annual emission rate in this study ($168 \pm 43 \text{ g bird-place}^{-1} \text{ yr}^{-1}$) agrees well with the value reported by Gates et al., (2008) for birds of 40 d of age and market weights 2.10 kg in built-up litter. However, the observed factors for N_2O and CH_4 in this study were higher, being 16 ± 4 and $61 \pm 16 \text{ g bird place}^{-1} \text{ year}^{-1}$, respectively, which is higher than the value observed by Burns et al., (2008) when considering litter reuse for up to six batches.

The values proposed by the IPCC for N_2O and CH_4 was also lower, however the IPCC does not consider the reuse of the litter. Although the values observed in this study differ from those observed in Brazilian studies, the factors observed by Miles et al. (2014) in reutilized litter confirm the observed factors for N_2O .

In addition, it should be emphasized that the emission factors presented in this study refer to the dark house production system with management of reuse of the broiler litter for a long period, differing from the practices adopted in other regions of the country.

Another aspect that can be pointed out are the methodologies used in other studies, such as that of Santana (2016) and Lima et al. (2015) which may contain high uncertainty related to sampling methods and determination of emissions.

Santana (2016) observed very low values for N_2O and CH_4 emissions, however the study was conducted in suspended cages and the animals were placed on a surface composed of a thin layer of substrate that was on a wire mesh. This aspect may have favored the litter aeration, as it allowed the passage of air through broiler litter in all directions.

The estimates used in this study for mature weight and age and the annual number of batches from a house are reasonable averages, however, seasonal, regional, and integrator practices do vary appreciably.

For the annual emission rate in relation to litter condition, considering its reuse or not, Gates et al., (2008) estimated a reduction of 27-47% in the emission rate of annual ammonia if new litter is utilized in each batch, but by replacing litter after each batch, the covered storage would be required and emission from this stored litter would also occur. Furthermore, it would result in a 5 to 10 fold increase in litter costs (assuming pricing remains constant) and transport fuel costs, and a similar increase in volume of litter to handle and store for future land application.

4.4.2. Emissions descriptors

Emissions fluxes showed that in the first week, the average fluxes of ammonia are considerable, differently from that observed in other studies performed with new litter. Calvet et al., (2011) observed insignificant emissions in the first weeks in the summer. Emissions began to move from day 20 and increased significantly until the end of the cycle, when the average was $40.1 \text{ mg bird}^{-1} \text{ h}^{-1}$. The average for the batch was $16.9 \text{ mg bird}^{-1} \text{ h}^{-1}$ and in this study was $21.49 \text{ mg bird}^{-1} \text{ h}^{-1}$.

For $\text{CO}_2\text{-C}$ emissions, approximately double of values in the first weeks were observed in this study, when compared to the values observed by Calvet et al., (2011). In this study the fluxes observed varied between 300 ± 66 and $582 \pm 169 \text{ mg bird}^{-1} \text{ h}^{-1}$ in the first week and 1550 ± 279 and $1991 \pm 276 \text{ mg bird}^{-1} \text{ h}^{-1}$ in the last week, while Calvet et al., (2011) observed values from 297 in the first week to $1557 \text{ mg bird}^{-1} \text{ h}^{-1}$ in the last week.

However, since the objective of the emission flux determination was to identify the variables that describe the emissions, and emission flux was not used to determine the emission rate, in this topic we will discuss in detail the variables that affected the emissions fluxes.

Knowing the variables that describe the emissions allows one to know, identify, and test practices that can minimize the emissions of gases. Many variables have already been described in the literature as responsible for increasing or decreasing emissions, but little is known about how litter reuse can affect the flux of emissions. The results obtained seem to indicate that litter reuse modifies the fluxes of elements making some variables more important than those widely described in the literature.

The results of the matrices tested show that some variables do not have the same effect on the emission flux of both gases. For the CO₂ flux, was observed that the external temperature, as well as the air velocity associated to the number of litter reuses and animal weight, explain the emissions better, whereas for NH₃ flux, a more pronounced effect of litter nitrogen, velocity, and weight of the animals, was observed and explain the flux of NH₃ better than other combinations. The increases N excretion per day per bird occasioned by increasing age and weight can lead to higher NH₃ emissions. It was observed in previous studies (MOORE et al., 2011) and remarkably in this study.

Birds tend to ingest more feed as they grow, so N consumption also increases, and, possibly, higher N excretion occurs through excreta. In addition, it may be the emission of these gases within the aviaries, which is always dependent on the metabolic efficiency of the animal and the quality of the food that is offered (WHEELER et al., 2006; MILES et al., 2011). Normally, broiler chickens tend to be inefficient as they reach maturity, taking less advantage of feed constituents, including N in the form of protein (HENN et al., 2015).

The age/weight of birds also influences CO₂ emissions rates, mostly by bird respiration. Henn et al., (2015) identified that the CO₂ production by bird respiration corresponds to about 43% of the C retained by the animals.

In addition, Calvet et al., (2011) observed that the flow of CO₂ emissions from litter corresponded to about 20% of the total flow observed during the study.

It is estimated here that CO₂ litter represented 25% of emissions. Lower values were observed in previous studies with new litter by Henn et al., (2015). This variation of contribution of CO₂ by the litter may vary depending on the litter material, the C:N ratio in the substrate, and the litter management (CALVET et al. 2011). This contribution may be particularly affected by reuse litter as compared with new bedding material.

The relationship between the age of the birds and CO₂ emissions rate was observed by Henn et al., (2015), Burns et al., (2008), Miles et al., (2006), Knizatova et al., (2010b), and confirmed by the current study, although, in this study, the model that best described the emissions presented the variable weight of the animals.

The reduced number of studies on CO₂ emissions from litter hinders discussion on aspects that may affect these emissions.

On the other hand, numerous studies point to a large number of variables that affect NH₃ emissions. Previous studies found a positive association between the nitrogen content associated with litter reuse and NH₃ emissions. In this study, the most pronounced effect was nitrogen content, indicating that the effect of nitrogen content has a more pronounced effect on emissions when litter is reused for more than a year. Models observed here were tested to verify that nitrogen content exerts a negative effect on the emissions, e.g., higher levels of N present in the litter were associated to lower flows of NH₃. This effect disagrees with current literature (WHEELER et al., 2006; GATES et al., 2008), as it is expected that as N increases in litter in combination with elevated pH, higher volatilization losses of NH₃ occur. Accumulation of excreta in litter raises the pH. Thus, with the lower the conversion of NH₃ to NH₄⁺, there is consequently the greater the losses of N in the form of NH₃.

According to Mosier (2004), the availability of N associated with litter pH and moisture are key factors for the production and emission of GHG and NH_3 . For Groot Koerkamp et al., (1998), this degradation reaction in litter of broiler houses involves about 8 to 40% of the total uric acid produced by birds per day. According to Elliot and Collins (1982), the pH, litter moisture, and litter temperature exert an influence on this reaction. Baião (1996) determined that the temperature between 25 ° and 30 ° C and the pH higher than 5.5 (ideal 9.0), in addition to the litter moisture content between 40 and 60%, contributed to the increase in the degradation of the nitrogen compounds in litter. This effect may have been masked by the small change in pH, observed during the production cycle. During the production cycles, pH was observed between 8 and 9, and it is believed that due to the small pH variation, the correlation between the pH and the emission flux did not occur.

In addition, this effect of nitrogen content on NH_3 emissions may be due to the homogeneity of total nitrogen concentrations in litter during the batch and between batches. The difference in initial nitrogen concentration between batches was in the range of 1 to 5 g kg^{-1} , whereas in a new litter the variation of the nitrogen content between the new and reused litter could be very large. Santana (2016) observed greater difference between the first and second litter reuse. However, this author also observed a negative effect of the N content on the emissions, but, there was an interaction effect between pH, nitrogen, and litter moisture.

A significant effect of litter moisture on NH_3 emissions was also observed in the matrices tested, but these effects were more discrete and did not appear in the matrix that best described the emissions. The effect of moisture was positive, but the order of proportion of increase of moisture content over flow was small when compared to the number of litter reuses, for example.

Guiziou and Béline (2005) reported that nitrogen losses from broiler houses calculated from nitrogen budget showed the influence of the litter quantity and environmental conditions on nitrogen behavior. Normally, reused litter has more nitrogen content. Brewer and Costello (1999) reported that ammonia flux from reused litter was six times higher than that from new bedding material at the start of a grow-out.

Wheeler et al., (2006) also observed that average emission rate over a batch increases with high stocking densities because the potential for higher ammonia emissions was associated with increased excretion of uric acid per litter area. In this study, stocking densities varied little between the batches and houses, and no correlation was verified.

Another variable that is cited in the literature as a potential to affect emissions is temperature. Temperature is a very important variable during the processes of ammonia emissions from litter. Air temperature may influence the convective mass transfer coefficient (SOMMER et al., 2006). Litter temperature may influence the diffusion and generation of ammonia in litter (LIU et al., 2006). Therefore, temperature variation can greatly affect ammonia flux. In the broiler houses, air temperature is usually managed to optimize bird health and productivity, and inside temperature decrease with bird age. In this sense, a negative correlation was observed in relation to the ambient temperature and the emissions of NH_3 and CO_2 , but the models with this variable do not satisfactorily explained the emissions.

On the other hand, for CO_2 emissions, it was observed that the outside temperature has strong influence, as well as air velocity. A positive effect was observed for the air velocity on the emissions of both gases.

Several authors have attributed climate differences as an indirect factor on emissions. Wheeler et al., (2006) and Casey et al., (2010) observed a seasonal effect, and within each batch, they observed an effect from bird age. For batches housed in summer, mean ammonia fluxes were almost double those from winter housed batches because of higher ventilation rates in the warmer weather (NICHOLSON et al., 2004).

Lacey et al., (2003) emphasized that different climatic conditions cause those different values of emission rates. Although Knizatova et al., (2010a) did not observe seasonal difference as a factor that had statistically significant difference in emissions of NH_3 or CO_2 , other studies have shown significant seasonal differences (WHEELER et al., 2006; BURNS et al., 2007; CALVET et al., 2011).

Harper et al., (2010) attributed the differences observed by season to change in air turbulence in the houses (i.e., ventilation) and the humidity of air between the houses.

Calvet et al., (2011) observed that the ventilation rates are strongly influenced by the outside temperature and attributed the differences observed in emissions of NH_3 between winter and summer to the indirect effect that the ventilation can have on the condition of the litter. For Harper et al., (2010), the ventilation (turbulence) can cause two different effects on emissions. First, it can increase emission rates by increasing the removal of diffusive gases from the source material, but, secondly, it can also dry litter and cause a diminution in posterior emissions.

In this study, the outside temperature had a negative effect on CO_2 emissions. The hypothesis in the case is that in summer observations, evaporative cooling increased humidity content in the air and resulted in the high moisture of litter during batches, however, the effect occurred in surface litter and not at all depths of the litter. Then, homogenizing the litter at the sampling can have occulted this effect. In addition, air saturation can affect mass transfer rates by imparting CO_2 to litter in these conditions. The ventilation rate also affects the NH_3 flux directly, as in all published values. The effect of air velocity on CO_2 emissions was also observed. The ventilation rate can be related with CO_2 emissions. Burns et al., (2008) observed significant correlation with the ventilation rate. Knizatova et al. (2010b) confirmed this relation to ventilation rate.

4.5. Conclusion

The average emissions rates for “Dark house” type broiler houses with intensive litter reuse (11-17 batches) were 0.63 ± 0.16 , 100.2 ± 16 , 0.23 ± 0.15 , and 0.06 ± 0.02 g bird⁻¹ d⁻¹ for NH_3 , CO_2 , CH_4 , and N_2O , respectively. Average annual emission rate obtained from all broiler houses and batches evaluated were higher than those observed in other Brazilian studies developed in new litter.

The emissions of NH_3 have been influenced by the bird weight, ventilation rate, period of day and, N concentration. The climatic condition can be an indirect effect of litter conditions because ventilation rates can foster conditions that may increase or decrease the emissions.

For the CO_2 , the emission have been influenced by the ventilation rate, outside temperature, and bird weight. It is estimated that the CO_2 fraction issued by the litter is 25%.

The ventilation rate seems to be an important descriptor of emissions of CO_2 and NH_3 , however, interactions and potential synergies or compensation between various effects may have occurred. More studies are needed to identify how the reuse of litter and ventilation indirectly affect the condition of the litter and possible interactions between other variables.

References

BAIÃO, N. C. Quando o ambiente fica carregado. **Revista Aves e Ovos**, São Paulo, p. 20-22, 1996.

- BARTON, L.; KIESE, R.; GATTER, D.; BUTTERBACK-BAHL, K.; BUCK, R.; HINZ, C.; MURPHY, D. V. Nitrous oxide emissions from a cropped soil in a semi-arid climate. **Global Change Biology**, Oxford, v. 14, p. 177-192, 2008.
- BREWER, S.K.; COSTELLO, T.A. In situ measurement of ammonia volatilization from broiler litter using an enclosed air chamber. **ASAE**, St. Joseph, v.42, n.5, p.1415-1422, 1999.
- BROUČEK J.; ČERMAK B. Emission of harmful gases from poultry farms and possibilities of their reduction. **Ekologia**, Bratislava, v.34, n.1, p.89-100, 2015.
- BROUČEK, J. Methods of methane measurement in ruminants. **Slovak Journal of Animal Science**, Slovak, v.47, n.1, p.51-60, 2014.
- BURNS, R. T.; XIN, H.; GATES, R.; LI, H.; HOFF, S.; MOODY, L.; OVERHULTS, D.; EARNEST, J. **Tyson Broiler Ammonia Emission Monitoring Project: Final Report**. Agricultural and biosystems engineering. Technical reports and with papers. Paper 15. 2007. Disponível em: <http://lib.dr.iastate.edu/abe_eng_reports/15>. Acessado em: 25 Agosto 2015.
- BURNS, R. T.; LI, H.; XIN, H.; GATES, R. S.; OVERHULTS, D. G.; EARNEST, J.; MOODY, L. B. Greenhouse gas (GHG) emissions from broiler houses in the southeastern United States. **ASABE**. St. Joseph, 2008.
- CALVET, S.; CAMBRA-LOPEZ, M.; ESTELLES, F.; TORRES A.G. Characterization of gas emissions from a Mediterranean broiler farm. **Poultry Science**, Oxford, v.90, p.534-542, 2011.
- CARVALHO, T. M. R.; MOURA, D. J.; SOUZA, Z. M. Qualidade da cama e do ar em diferentes condições de alojamento de frangos de corte. **Pesquisa Agropecuária Brasileira, Brasília**, v.46, n.4, p.351-361, 2011.
- CASEY, K. D.; GATES, R. S.; SHORES, R. C.; THOMA, E. D.; HARRIS, D. B. Ammonia Emissions from a US Broiler House - Comparison of Concurrent Measurements Using Three Different Technologies. **Journal of the Air & Waste Management Association**, Philadelphia, v.60, n.8, p.939-948, 2010.
- CASEY, K.D.; GATES, R.S.; WHEELER, E.F.; ZAJACZKOWSKI, J.S; TOPPER, P.A.; XIN, H.; LIANG. Y.; Ammonia emissions from broiler houses in Kentucky during winter. In: International Symposium on Gaseous and Odour Emissions from Animal Production Facilities. **Proceedings...** Denmark. June 1-4, 2003.
- CHADWICK, D. R.; SNEATH, R. W.; PHILLIPS, V. R.; PAIN, B. F. A UK inventory of nitrous oxide emissions from farmed livestock. **Atmospheric Environment**, Oxford, v. 33, p. 3345-3354, 1999.
- ELLIOT, H. A.; COLLINS, N. E. Factors affecting ammonia release in broiler houses. **Transactions of the ASAE**, St. Joseph, v. 25, p. 413-424, 1982.
- GATES, R. S.; CASEY, K. D.; WHEELER, E. F.; XIN, H.; PESCATORE, A. J. U. S. Broiler housing ammonia emissions inventory. **Atmospheric Environment**, Oxford, v. 42, p. 3342-3350, 2008.
- GROOT KOERKAMP, P. W. G.; METZ, J. H. M.; UENK, G. H. ; PHILLIPS, V. R.; HOLDEN, M. R; SNEATH, R. W.; SHORT, J. L.; WHITE, R. P.; HARTUNG, J.; SEEDORF, J.; SCHRODER, M.; LINKERT, K. H.; PEDERSEN, S.; TAKAI, H.; JOHNSEN, J. O.; WATHES, C. M. Concentrations and emissions of ammonia in livestock buildings in Northern Europe. **Journal Agricultural Engineering Research**. v.70, p.79-95, 1998.
- GUIZIOU, F.; BÉLINE, F. In situ measurement of ammonia and greenhouse gas emissions from broiler house in France. **Bioresource Technology**, Amsterdam, v. 96, p. 203-207, 2005.
- HARPER, L. A.; FLESCHE, T.K; WILSON, J. D. Ammonia emissions from broiler production in the San Joaquin Valley. **Poultry Science**, Oxford. 89, p.1802-1814, 2010.

- HENN, J. D.; BOCKOR, L.; BORILLE, R.; COLDEBELLA, A.; RIBEIRO, A. M. L.; KESSLER, A. M. Determination of the equation parameters of carbon flow curves and estimated carbon flow and CO₂ emissions from broiler production. **Poultry science**, Oxford, v.94, n.9, p.2303-2312, 2015.
- IPCC. **Scientific Assessment**. Cambridge: Cambridge University Press, 2006.
- JEPPSSON, K.H. Volatilization of ammonia in deep litter systems with different bedding materials for young cattle. **Journal of Agricultural Engineering Research**, Salt Lake City v.7, p.49-57, 1999.
- KNIŽATOVA, M.; BROUČEK, J.; MIHINA Š. Seasonal differences in levels of carbon dioxide and ammonia in broiler housing. **Slovak Journal of Animal Science**, Slovak, v.43, p.105–112, 2010a.
- KNIŽATOVA, M.; MIHINA, Š.; BROUČEK, J.; KARANDUŠOVSKA, I.; MAČUHOVA J. Ammonia emissions from broiler housing facility: influence of litter properties and ventilation. In XVIII World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR). Canadian Society for Bioengineering (CSBE/ SCGAB). **Proceedings...** Quebec, Canada, 2010b.
- KNIŽATOVA, M.; MIHINA, Š.; BROUČEK, J.; KARANDUŠOVSKA, I.; MAČUHOVA J. The influence of litter age, litter temperature and ventilation rate on ammonia emissions from a broiler rearing facility. **Czech Journal of Animal Science**, Czech, v.55, p.337–345, 2010c.
- LACEY, R. E.; REDWINE, J. S.; PARNELL JUNIOR, C. B. Particulate matter and ammonia emission factors for tunnel-ventilated broiler production houses in the southern U.S. **Transactions of the ASAE**, St. Joseph, v. 46, p. 1203-1214, 2003.
- LIMA, K. A. O.; MOURA, D. J.; CARVALHO, T. M. R.; BUENO, L. G. F.; VERCELLINO, R. A. Ammonia emissions in tunnel-ventilated broiler houses. **Brazilian Journal of Poultry Science**, Campinas, v. 13, p. 265-270, 2011.
- LIMA, N. D. S.; GARCIA, R. G.; NÄÄS, I. A.; CALDARA, F. R.; PONSO, R. Model predicted ammonia emission from two broiler houses with different rearing systems. **Scientia Agricola**, Piracicaba, v. 72, p. 393-399, 2015.
- LIN, X. J.; CORTUS, E. L.; ZHANG, R.; JIANG, S.; HEBER, A. J. Air emissions from broiler houses in California. **Transactions of the ASABE**, St. Joseph, v. 55, p. 1895-1908, 2012.
- MÉDA, B.; HASSOUNA, M.; LECOMTE, M.; GERMAIN, K.; DOURMAD, J.Y.; ROBIN, P. Influence of season and outdoor run characteristics on excretion behaviour of organic broilers and gaseous emissions. **Biosystems Engineering**, Amsterdam v.139, (11) p.35–47, 2015.
- MENDES, L.; TINOCO, I.; OGINK, N.; ROCHA, K.; OSORIO, J.; SANTOS, M. Ammonia emissions from a naturally and a mechanically ventilated broiler house in Brazil. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 18, p. 1179-1185, 2014.
- MENEGALI, I.; TINÓCO, I.F.F.; ZOLNIER, S.; CARVALHO, C.C.S.; GUIMARÃES, M.C.C. Influence of different systems of minimum ventilation on air quality in broiler houses. **Engenharia Agrícola**, Campinas, v.32, p.1024-1033, 2012.
- MIHINA, Š.; KNIŽATOVA, M.; BROUČEK J. Effect of season on carbon dioxide and ammonia production in broiler housing. In Selected problems of soil tillage systems and operations Warsaw: **Faculty of Production Engineering**, Warsaw University of life Sciences, p. 123–133, 2010.
- MILES, D. M.; OWENS, P. R.; ROWE, D. E. Spatial variability of litter gaseous flux within a commercial broiler house: ammonia, nitrous oxide, carbon dioxide, and methane. **Poultry Science**, Oxford, v. 85, p. 167-172, 2006.
- MILES, D.M. et al. Winter broiler litter gases and nitrogen compounds: temporal and spatial trends. **Atmospheric Environment**, Amsterdam, v.42, n.14, p.3351-3363, 2008.

- MILES, D. M.; BROOKS, J. P.; SISTANI, K. Spatial contrasts of seasonal and intraflok broiler litter trace gas emissions, physical and chemical properties. **Journal of Environmental Quality**, Madison, v. 40, p. 176-87, 2011.
- MILES, D. M.; MOORE, P. A.; BURNS, R. T.; BROOKS, J. P. Ammonia and nitrous oxide emissions from a commercial broiler house. **Journal of environmental quality**, Madison, v.43(4), p.1119-1124, 2014.
- MIRAGLIOTTA, M. Y.; NÄÄS, I. A.; MURAYAMA, M. C.; MOURA, D. J. Software para estimativa de emissão de amônia em alojamento de frangos de corte. **Revista Brasileira de Agroinformática**, São Paulo, v. 6, p. 79-89, 2004.
- MOORE, P. A. Best management practices for poultry manure utilization that enhance agricultural productivity and reduce pollution. In: **Animal Waste Utilization: Effective Use of Manure as a Soil Resource**. J. L. Hatfield and B. Stewart, ed. Ann Arbor Press, Chelsea, MI. P. 89–117, 1998.
- MOORE, P. A.; MILES, D.; BURNS, R.; POTE, D.; BERG, K.; CHOI, I. H. Ammonia emission factors from broiler litter in barns, in storage, and after land application. **Journal of environmental quality**, Madison, v. 40, n.5, p.1395-1404, 2011.
- MOSIER, A.; WASSMAN, R.; VERCHOT, L.; KINK, J.; PALM, C. **Methane and nitrogen oxide fluxes in tropical agricultural soils: sources, sinks and mechanisms**. Dordrecht: Springer, p. 11-49, 2004.
- NICHOLSON, F.A.; CHAMBERS, B.J.; WALKER, A.W. Ammonia emissions from broiler litter and laying hen manure management systems. **Biosystems Engineering**. Oxford, v.89, n.2, p175-185, 2004.
- PAILLAT, J. M.; ROBIN, P.; HASSOUNA, M.; LETERME, P. Predicting ammonia and carbon dioxide emissions from carbon and nitrogen biodegradability during animal waste composting. **Atmospheric environment**, Oxford, v.39, n. 36, p.6833-6842, 2005.
- PESCATORE, A. J.; CASEY, K. D.; GATES, R. S. Ammonia emissions from broiler houses. **Journal of Applied Poultry Research**, Athens, GA, v. 14, p. 635-637, 2005.
- PONCHNT, P.; HASSOUNA, M.; EHRLACHER, A.; AUBERT, C.; AMAND, G. LELEU, C.; ROBIN, P. Application et validation d'une méthode de mesures simplifiées des émissions gazeuses dans les bâtiments d'élevage à ventilation naturelle. **TeMa**, Paris, v.6. p4-10, 2008.
- REDDING, M.R. Bentonite can decrease ammonia volatilisation losses from poultry litter: laboratory studies. **Animal Production Science**, Oxford, v. 53, p. 1115–1118. 2013.
- SANTANA, I. K. S. DA. Emissões de gases de efeito estufa e amônia oriundas da criação de frangos de corte em múltiplos reúsos da cama. 2016. 130p. **Tese** (Doutorado em Energia nuclear na agricultura) - Universidade de São Paulo, Piracicaba, 2016.
- SNEATH, R. W.; PHILLIPS, V. R.; DEMMERS, T. G. M.; BUERGESS, L. R.; SHORT, J. L.; WELCH, S. K. Long term measurements of greenhouse gas emissions from UK livestock buildings. In: INTERNATIONAL SYMPOSIUM ON LIVESTOCK ENVIRONMENT, 5., 1997, Bloomington. **Proceedings...** Bloomington, 1997. p. 146- 153.
- SOMMER, S.G.; ZHANG, G.Q.; BANNINK, A.; CHADWICK, D.; MISSELBROOK, T.; HARISON, R.; HUTCHINGS, N.J.; MENZI, H.; MONTENY, G.J.; NI, J.Q.; OENEMA, O.; WEBB, J. Algorithms determining ammonia emission from buildings housing cattle and pigs and from manure stores. **Advances in Agronomy**, Madison, v.89, p.261-335, 2006.
- XIN, H.; GATES, R. S.; GREEN, A. R.; MITLOEHNER, F. M.; MOORE, P. A.; WATHES, C. M. Environmental impacts and sustainability of egg production systems. **Poultry Science**. v.90, p.267–277, 2011.

- WALKER, J.T.; ROBARGE, W.P.; AUSTIN R. Modeling of ammonia dry deposition to a pocosin landscape downwind of a large poultry facility. **Agriculture, Ecosystems and Environment**, Amsterdam v.185, p.161–175, 2014.
- WANG, S. Y.; HUANG, D. J. Assessment of greenhouse gas emissions from poultry enteric fermentation. **Asian-Australasian Journal of Animal Sciences**, Seoul, v. 18, p. 873-878, 2005.
- WHEELER, E.; CASEY, K.; GATES, R. S.; XIN, H.; ZAJACZKOWSKI, J. L.; TOPPER, P. A.; LIANG, Y.; PESCATORE, A. J. Ammonia emissions from twelve U.S.A. broiler chicken houses. **Transactions of the ASAE**, St. Joseph, v. 49, p. 1495-1502, 2006.
- WOOD, D. COWHERD, S. HEYST, B.V. A summary of ammonia emission factors and quality criteria for commercial poultry production in North America. **Atmospheric Environment**, Oxford, v.115, n. 8, p.236–245, 2015.

5. GENERAL CONCLUSIONS AND FINAL REMARKS

Considering that the main objective of this study was to determine emissions factors of broiler houses with reused litter utilizing a simplified method, some considerations can be made.

Direct quantification and monitoring of gaseous emissions in poultry production systems has been a major challenge facing the scientific community. The main problem is related to the lack of methodological standardization and the cost of applying the continuous methodologies. It is, therefore, important to develop and apply simplified methodologies that allow the application and quantification of emissions in a large number of production systems. In this study, we used a simplified methodology developed in France, which has been adapted and applied to several French production systems (swine, poultry, and cattle). In Brazil, this methodology was recently applied by Tavares (2016) for the determination of gas emissions in pig production and never before applied to the production of broilers. This methodology is based on the principle of concentration ratio. The concentration ratio method is considered a robust method and presented satisfactory results during water balance validation. The mass balance also presented very satisfactory results when verified by the balance of phosphorus.

Nevertheless, it is important to highlight that, as in any other method, uncertainties are present, although the equipment and protocol of air sampling are robust and applicable to several situations, the use of mean values can lead to uncertainty in the results if the balance mass is not accurate.

Additionally, it is possible that the outside conditions (temperature, humidity) and / or the building management system (litter revolving, opening of the air intakes) can promote exceptional gas emissions and can cause altered conditions. Although precaution has been taken to ensure that the variations caused by changes in temperature and ventilation in the houses have been accounted (sampling in the morning and afternoon), we also chose to carry out the samplings in different producers and repeated batches to present the most representative average emission factor possible.

Another aspect that should be taken into account is the sampling bag because although it is presented as a robust method, it may be difficult to maintain them without any modification of the gas concentrations. In this study, special care was taken to reduce these uncertainties related to transportation of the bags and the type of bags used, in addition to the time between the air sampling and the determination of the emissions that was at most between 3 and 4 hours.

Against this complexity in GHG measurements in poultry farming and the diversity of aspects that can influence emissions in an production environment, the greatest challenge in this research was to develop a data collection protocol that would allow for the monitoring of the greatest number possible of dark houses, greater number of batches in the given time, interval between data collection and gas determination, in addition to the availability of budget and equipment.

Emission rates presented here relate only to the production stage, usually called "gateway" in life cycle analyzes. Our evaluation did not include the stages of grain production, transport, room heating/cooling and industrialization, stages of litter storage, maturation, and soil application.

In part I of this study, environment of broiler houses and management conditions was available, and we observed that litter reuse had no effect on air quality. Although in some moments, higher concentrations and high values of enthalpy were observed, but these aspects did not negatively affect the performance of the batches.

The emissions of methane were higher when compared to data presented in the literature, in which studies were conducted with new litter. The aspect that most likely contributed to these methane emissions was the formation of anaerobic litter regions, most probably due to the litter height, which varied between 10 and 30 cm.

Average annual emission rate obtained from all broiler houses and batches evaluated were higher than those observed in other Brazilian studies developed with new litter or litter reused a few times. However, when comparing with data from other countries, some emission rates were similar. Average emissions rates for “Dark house” type broiler houses with intensive litter reuse were 0.63 ± 0.16 , 100.2 ± 16 , 0.23 ± 0.15 , and 0.06 ± 0.02 g bird⁻¹ d⁻¹ for NH₃, CO₂, CH₄, and N₂O, respectively.

In addition, the combinations of different variables through the theory of mixed models in this study allowed us to identify variables that had a greater influence on emissions, representing a practical contribution to possible improvements in production systems for the purpose of emissions reduction.

In general, the results of this research confirm the hypothesis that litter reuse increases gaseous emissions. N and C balances performed in this study demonstrated that losses were higher than those observed in studies performed with a new litter.

However, to assure environmental sustainability and lower production costs, more studies are needed to identify the real effect of litter reuse on emissions, as well as to evaluate the impact of litter change compared to reuse for long periods.

APPENDIX

Appendix A. Linear mixed models tested to identify the variables that describe CO₂ emission fluxes.

(continued)

Type	Variables	N_Parameter s	_NAM E_	_2_Res_Log_Likeliho od
Linear	Intercepto+Weight+Weight ² +Batch+te+Veloci	6	Value	1512.6
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Veloci+te	6	Value	1512.9
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Veloci+Batch	6	Value	1513.2
Linear	Intercepto+Weight+veloci+te+C_litter+Batch	6	Value	1514.8
Linear	Intercepto+Weight+veloci+te+C_litter+Batch	6	Value	1515.5
Linear	Intercepto+Weight+veloci+te+N_litter_g_kg+N_litter_g_kg ²	6	Value	1515.7
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Veloci+Umid_litter	6	Value	1515.9
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Veloci+temp	6	Value	1515.9
Linear	Intercepto+Weight+veloci+te+C_litter+Umid_litter	6	Value	1516.1
Linear	Intercepto+Weight+veloci+te+C_litter+N_litter_g_kg	6	Value	1516.1
Linear	Intercepto+Weight+veloci+te+C_litter+he	6	Value	1518.2
Linear	Intercepto+Weight+Weight ² +Batch+te+N_litter_g_kg	6	Value	1518.6
Linear	Intercepto+Weight+Weight ² +Rel_C_N+Veloci+te	6	Value	1518.7
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Veloci+umid	6	Value	1520.8
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Veloci+he	6	Value	1522.2
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Veloci+Ent_ext	6	Value	1523.3
Linear	Intercepto+broiler_house+Weight+Batch+te+Veloci	6	Value	1523.3
Linear	Intercepto+broiler_house+Weight+Batch+Batch+Weight ²	6	Value	1523.4
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Batch	5	Value	1525.4
Linear	Intercepto+Weight+veloci+te+C_litter+broiler_house	6	Value	1525.8
Linear	Intercepto+Weight+veloci+te+C_litter	5	Value	1525.8
Linear	Intercepto+Weight+Weight ² +Batch+te+Batch	6	Value	1525.9
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Veloci	5	Value	1526.3
Linear	Intercepto+broiler_house+Weight+Batch+Weight ² +veloci	6	Value	1524.5
Linear	Intercepto+broiler_house+Weight+Batch+veloci+Weight ²	6	Value	1524.5
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Umid_litter	5	Value	1526.6
Linear	Intercepto+broiler_house+Weight+Batch+Weight ² +temp	6	Value	1525.0
Linear	Intercepto+broiler_house+Weight+Batch+te+ Weight ²	6	Value	1525.5
Linear	Intercepto+Weight+Weight ² +Batch+te+Broiler_house	6	Value	1525.5
Linear	Intercepto+broiler_house+Weight+Batch+Weight ² +te	6	Value	1525.5
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+temp	5	Value	1528.1

Appendix A. Linear mixed models tested to identify the variables that describe CO₂ emission fluxes.

(continued)

Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Veloci+Broiler_house	6	Value	1526.1
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Batch	5	Value	1528.2
Linear	Intercepto+Weight+N_litter_g_kg+te+Umid_litter	5	Value	1528.3
Linear	Intercepto+Weight+Weight ² +Batch+te+temp	6	Value	1528.4
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Veloci+Ent_interna	6	Value	1528.5
Linear	Intercepto+broiler_house+Weight+Batch+Weight ² +Umid_litter	6	Value	1527.1
Linear	Intercepto+Weight+veloci+temp+N_litter_g_kg	5	Value	1529.2
Linear	Intercepto+broiler_house+Weight+Batch+Batch+temp	6	Value	1527.3
Linear	Intercepto+Weight+veloci+te+C_litter+Ent_ext	6	Value	1529.5
Linear	Intercepto+broiler_house+Idade+Batch+te+Veloci	6	Value	1527.6
Linear	Intercepto+Weight+veloci+te+C_litter+Ent_interna	6	Value	1529.9
Linear	Intercepto+broiler_house+Weight+Batch+Batch+Veloci	6	Value	1528.2
Linear	Intercepto+broiler_house+Weight+Batch+Batch+Umid_litter	6	Value	1528.3
Linear	Intercepto+Weight+Weight ² +Batch+te+he	6	Value	1530.6
Linear	Intercepto+Weight+Batch+temp+N_litter_g_kg	5	Value	1531.0
Linear	Intercepto+broiler_house+Weight+Batch+Batch+Weight*turno	6	Value	1529.1
Linear	Intercepto+broiler_house+Weight+Batch+te+ Umid_litter	6	Value	1529.4
Linear	Intercepto+Weight+veloci+te+Umid_litter	5	Value	1531.5
Linear	Intercepto+broiler_house+Weight+Batch+te+ turno	6	Value	1529.8
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+umid	5	Value	1531.8
Linear	Intercepto+Weight+veloci+te+Rel_C_N	5	Value	1531.8
Linear	Intercepto+Weight+Weight ² +Batch+te+umid	6	Value	1531.9
Linear	Intercepto+Weight+C_litter+temp+N_litter_g_kg	5	Value	1531.9
Linear	Intercepto+broiler_house+Weight+Batch+te+ temp	6	Value	1530.5
Linear	Intercepto+Weight+Batch+te+N_litter_g_kg	5	Value	1532.5
Linear	Intercepto+broiler_house+Idade+Batch+Batch+Veloci	6	Value	1530.6
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+he	5	Value	1533.1
Linear	Intercepto+Weight+veloci+te+temp	5	Value	1534.0
Linear	Intercepto+broiler_house+Idade+Batch+Batch+temp	6	Value	1533.3
Linear	Intercepto+Weight+Weight ² +C_litter+te	5	Value	1535.3
Linear	Intercepto+Weight+C_litter+te+N_litter_g_kg	5	Value	1535.6
Linear	Intercepto+Weight+N_litter_g_kg+te+C_litter	5	Value	1535.6
Linear	Intercepto+Weight+Weight ² +C_litter+Veloci	5	Value	1535.6

Appendix A. Linear mixed models tested to identify the variables that describe CO₂ emission fluxes.

(continued)

Linear	Intercepto+Weight+he+temp+N_litter_g_kg	5	Value	1535.6
Linear	Intercepto+Weight+he+te+N_litter_g_kg	5	Value	1535.7
Linear	Intercepto+broiler_house+Weight+Batch+te+he	6	Value	1533.9
Linear	Intercepto+Weight+veloci+te+he	5	Value	1536.0
Linear	Intercepto+broiler_house+Idade+Batch+Batch+Umid_litter	6	Value	1534.8
Linear	Intercepto+Weight+veloci+te+umid	5	Value	1537.0
Linear	Intercepto+broiler_house+Weight+Batch+Ent_ext+Veloci	6	Value	1535.0
Linear	Intercepto+Weight+Weight ² +Rel_C_N+Batch	5	Value	1537.0
Linear	Intercepto+Weight+Weight ² +Rel_C_N+te	5	Value	1537.1
Linear	Intercepto+broiler_house+Weight+Batch+te+C_litter	6	Value	1535.1
Linear	Intercepto+Weight+Weight ² +C_litter+Batch	5	Value	1537.1
Linear	Intercepto+Weight+Weight ² +Batch+te	5	Value	1537.2
Linear	Intercepto+Weight+Batch+te+ Weight ²	5	Value	1537.2
Linear	Intercepto+Weight+Weight ² +Rel_C_N+Batch	5	Value	1537.2
Linear	Intercepto+broiler_house+Weight+Batch+Weight ²	5	Value	1535.4
Linear	Intercepto+broiler_house+Weight+Batch+Batch+umid	6	Value	1535.7
Linear	Intercepto+Weight+Weight ² +Rel_C_N+Veloci	5	Value	1537.8
Linear	Intercepto+broiler_house+Idade+Batch+te+ temp	6	Value	1536.0
Linear	Intercepto+broiler_house+Weight+Batch+te+ umid	6	Value	1536.2
Linear	Intercepto+Weight+Weight ² +Rel_C_N+Umid_litter	5	Value	1538.3
Linear	Intercepto+broiler_house+Idade+Batch+Batch+Idade*turno	6	Value	1536.5
Linear	Intercepto+broiler_house+Idade+Batch+te+ Umid_litter	6	Value	1536.9
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Broiler_house	5	Value	1536.9
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Ent_ext	5	Value	1539.0
Linear	Intercepto+broiler_house+Idade+Batch+Batch+umid	6	Value	1537.2
Linear	Intercepto+Weight+Batch+te+C_litter	5	Value	1539.2
Linear	Intercepto+broiler_house+Idade+Batch+te+he	6	Value	1537.6
Linear	Intercepto+Weight+C_litter+te+Umid_litter	5	Value	1539.6
Linear	Intercepto+Weight+Weight ² +Batch+C_litter	5	Value	1539.6
Linear	Intercepto+Weight+Weight ² +Rel_C_N+temp	5	Value	1539.8
Linear	Intercepto+broiler_house+Weight+Batch+Ent_ext+ Weight ²	6	Value	1538.0
Linear	Intercepto+broiler_house+Weight+Batch+temp	5	Value	1538.1
Linear	Intercepto+Weight+Batch+Weight ² +Veloci	5	Value	1540.1
Linear	Intercepto+Weight+Weight ² +Batch+Veloci	5	Value	1540.1
Linear	Intercepto+broiler_house+Idade+Batch+te+C_litter	6	Value	1538.4
Linear	Intercepto+Weight+Batch+te+Umid_litter	5	Value	1540.8
Linear	Intercepto+broiler_house+Idade+Batch+te+ umid	6	Value	1539.0
Linear	Intercepto+Weight+Weight ² +Batch+temp	5	Value	1541.1

Linear	Intercepto+Weight+Weight ² +Batch+Batch	5	Value	1541.2
Linear	Intercepto+Weight+Weight ² +C_litter+Umid_litter	5	Value	1541.4
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Ent_interna	5	Value	1541.5
Linear	Intercepto+Weight+N_litter_g_kg+temp	4	Value	1541.9
Linear	Intercepto+Weight+Umid_litter+temp+N_litter_g_kg	5	Value	1541.9
Linear	Intercepto+broiler_house+Weight+Batch+Batch	5	Value	1540.0
Linear	Intercepto+broiler_house+Weight+Batch+Ent_interna+ Weight ²	6	Value	1540.2
Linear	Intercepto+broiler_house+Weight+Batch+Weight ² +Ent_inter na	6	Value	1540.2
Linear	Intercepto+broiler_house+Weight+Batch+Umid_litter	5	Value	1540.3
Linear	Intercepto+Weight+veloci+te	4	Value	1542.3
Linear	Intercepto+Weight+Weight ² +Batch+te+Ent_ext	6	Value	1542.4
Linear	Intercepto+broiler_house+Weight+Batch+te	5	Value	1540.7
Linear	Intercepto+broiler_house+Weight+Batch+Veloci	5	Value	1541.1
Linear	Intercepto+Weight+N_litter_g_kg+te	4	Value	1543.4
Linear	Intercepto+Weight+Umid_litter+te+N_litter_g_kg	5	Value	1543.4
Linear	Intercepto+broiler_house+Weight+Batch+Ent_interna+Veloci	6	Value	1541.6
Linear	Intercepto+Weight+Weight ² +Rel_C_N+umid	5	Value	1544.2
Linear	Intercepto+broiler_house+Weight+Batch+Ent_ext+ turno	6	Value	1542.3
Linear	Intercepto+Weight+he+te+C_litter	5	Value	1544.4
Linear	Intercepto+Weight+Weight ² +Batch+Umid_litter	5	Value	1544.5
Linear	Intercepto+broiler_house+Weight+Batch+Ent_ext+ Umid_litter	6	Value	1542.5
Linear	Intercepto+broiler_house+Idade+Batch+Batch	5	Value	1542.5
Linear	Intercepto+Weight+Weight ² +C_litter+umid	5	Value	1544.7
Linear	Intercepto+Weight+Weight ² +C_litter+he	5	Value	1544.8
Linear	Intercepto+Weight+Weight ² +Rel_C_N+he	5	Value	1544.9
Linear	Intercepto+broiler_house+Idade+Batch+Batch+Idade ²	6	Value	1543.0
Linear	Intercepto+Weight+Weight ² +Batch+te+Ent_interna	6	Value	1545.1
Linear	Intercepto+broiler_house+Idade+Batch+Veloci	5	Value	1543.6

Appendix A. Linear mixed models tested to identify the variables that describe CO₂ emission fluxes.

(continued)

Linear	Intercepto+broiler_house+Weight+Batch+Ent_ext+ Temp	6	Value	1543.8
Linear	Intercepto+broiler_house+Weight+Batch+Ent_ext+veloci+Weight*Ent_ext	7	Value	1543.9
Linear	Intercepto+broiler_house+Weight+Batch+Ent_interna+ turno	6	Value	1543.9
Linear	Intercepto+broiler_house+Idade+Batch+veloci+Idade ²	6	Value	1544.0
Linear	Intercepto+Weight+Ent_ext+temp+N_litter_g_kg	5	Value	1546.1
Linear	Intercepto+broiler_house+Idade+Batch+temp	5	Value	1544.4
Linear	Intercepto+broiler_house+Idade+Batch+te	5	Value	1544.5
Linear	Intercepto+broiler_house+Weight+Batch+Ent_interna+ Umid_litter	6	Value	1544.7
Linear	Intercepto+broiler_house+Idade+Batch+te+ Idade ²	6	Value	1544.8
Linear	Intercepto+Weight+Ent_ext+te+N_litter_g_kg	5	Value	1547.0
Linear	Intercepto+broiler_house+Weight+Batch+Ent_interna+ Temp	6	Value	1545.2
Linear	Intercepto+Weight+Weight ² +C_litter+Broiler_house	5	Value	1545.2
Linear	Intercepto+broiler_house+Idade+Batch+Ent_interna+Veloci	6	Value	1545.3
Linear	Intercepto+Weight+he+te+Umid_litter	5	Value	1547.4
Linear	Intercepto+Idade+Veloci+te	4	Value	1547.6
Linear	Intercepto+Weight+veloci+te+Ent_ext	5	Value	1547.8
Linear	Intercepto+Weight+Ent_interna+temp+N_litter_g_kg	5	Value	1547.9
Linear	Intercepto+Weight+C_litter+temp	4	Value	1548.1
Linear	Intercepto+broiler_house+Weight+Batch+C_litter	5	Value	1546.1
Linear	Intercepto+Weight+Weight ² +Batch+umid	5	Value	1548.3
Linear	Intercepto+Weight+Weight ² +Batch+he	5	Value	1548.5
Linear	Intercepto+broiler_house+Idade+Batch+Umid_litter	5	Value	1546.7
Linear	Intercepto+Weight+Weight ² +C_litter	4	Value	1548.9
Linear	Intercepto+Weight+Ent_interna+te+N_litter_g_kg	5	Value	1549.0
Linear	Intercepto+broiler_house+Weight+Batch+Ent_ext+ umid	6	Value	1547.2
Linear	Intercepto+Weight+Weight ² +Rel_C_N+Broiler_house	5	Value	1547.4
Linear	Intercepto+broiler_house+Weight+Batch+Ent_ext+C_litter	6	Value	1547.6
Linear	Intercepto+broiler_house+Idade+Batch+Ent_interna+ turno	6	Value	1547.7
Linear	Intercepto+broiler_house+Weight+Batch+umid	5	Value	1547.7

Appendix A. Linear mixed models tested to identify the variables that describe CO₂ emission fluxes.

(continued)

Linear	Intercepto+Weight+veloci+te+Ent_interna	5	Value	1550.0
Linear	Intercepto+broiler_house+Weight+Batch+he	5	Value	1548.1
Linear	Intercepto+broiler_house+Idade+Batch+C_litter	5	Value	1548.1
Linear	Intercepto+Weight+C_litter+te	4	Value	1550.3
Linear	Intercepto+Weight+Weight ² +te	4	Value	1550.3
Linear	Intercepto+Weight+Batch+Ent_ext+ Weight ²	5	Value	1550.4
Linear	Intercepto+Weight+Weight ² +Batch+Ent_ext	5	Value	1550.4
Linear	Intercepto+broiler_house+Weight+Batch+Ent_interna+C_litter	6	Value	1548.7
Linear	Intercepto+broiler_house+Weight+Batch+Ent_interna+ umid	6	Value	1548.9
Linear	Intercepto+Weight+Batch+te	4	Value	1551.0
Linear	Intercepto+Weight+Weight ² +Rel_C_N+Ent_ext	5	Value	1551.1
Linear	Intercepto+broiler_house+Weight+Batch+Ent_ext+he	6	Value	1549.2
Linear	Intercepto+broiler_house+Idade+Batch+umid	5	Value	1549.6
Linear	Intercepto+Weight+veloci+temp	4	Value	1551.6
Linear	Intercepto+Weight+Umid_litter+te	4	Value	1552.1
Linear	Intercepto+Weight+Batch+te	4	Value	1552.4
Linear	Intercepto+broiler_house+Idade+Batch+he	5	Value	1550.5
Linear	Intercepto+Weight+Weight ² +C_litter+Ent_interna	5	Value	1552.6
Linear	Intercepto+broiler_house+Idade+Batch+Ent_interna+ Temp	6	Value	1550.6
Linear	Intercepto+Weight+Batch+Weight ²	4	Value	1552.7
Linear	Intercepto+broiler_house+Weight+Batch+Ent_interna+he	6	Value	1550.9
Linear	Intercepto+Weight+Weight ² +Veloci	4	Value	1553.1
Linear	Intercepto+Weight+Batch+temp	4	Value	1553.3
Linear	Intercepto+Weight+Weight ² +Batch	4	Value	1553.4
Linear	Intercepto+broiler_house+Idade+Batch+Ent_interna+ Umid_litter	6	Value	1551.5
Linear	Intercepto+broiler_house+Idade+Batch+Ent_interna+C_litter	6	Value	1551.9
Linear	Intercepto+broiler_house+Weight+Batch1	4	Value	1551.9
Linear	Intercepto+Weight+Weight ² +temp	4	Value	1554.4
Linear	Intercepto+Idade+Veloci+C_litter	4	Value	1554.9
Linear	Intercepto+broiler_house+Weight+Batch+Ent_ext	5	Value	1553.1
Linear	Intercepto+Weight+Weight ² +Rel_C_N+Ent_interna	5	Value	1555.5
Linear	Intercepto+Weight+Batch+temp	4	Value	1555.7

Appendix A. Linear mixed models tested to identify the variables that describe CO₂ emission fluxes.

(continued)

Linear	Intercepto+broiler_house+Idade+Batch+Ent_interna+ umid	6	Value	1554.1
Linear	Intercepto+Weight+Batch+C_litter	4	Value	1556.4
Linear	Intercepto+broiler_house+Idade+Batch1	4	Value	1554.4
Linear	Intercepto+Weight+Ent_ext+te+C_litter	5	Value	1556.6
Linear	Intercepto+Idade+Batch+te+ Idade ²	5	Value	1556.6
Linear	Intercepto+Weight+Weight ² +Umid_litter	4	Value	1556.7
Linear	Intercepto+Weight+Batch+Batch	4	Value	1556.7
Linear	Intercepto+broiler_house+Idade+Batch+Idade ²	5	Value	1554.8
Linear	Intercepto+Weight+Umid_litter+temp	4	Value	1557.0
Linear	Intercepto+broiler_house+Idade+Batch+Ent_interna+he	6	Value	1555.0
Linear	Intercepto+broiler_house+Weight+Batch+Ent_interna	5	Value	1555.0
Linear	Intercepto+Weight+Ent_interna+te+C_litter	5	Value	1557.1
Linear	Intercepto+Weight+Batch+Ent_interna+ Weight ²	5	Value	1557.2
Linear	Intercepto+Weight+Weight ² +Batch+Ent_interna	5	Value	1557.2
Linear	Intercepto+Weight+Batch+Umid_litter	4	Value	1557.3
Linear	Intercepto+Weight+he+te	4	Value	1558.5
Linear	Intercepto+Idade+Veloci+temp	4	Value	1558.5
Linear	Intercepto+Idade+Veloci+Batch	4	Value	1558.6
Linear	Intercepto+Idade+Veloci+Batch	4	Value	1559.4
Linear	Intercepto+Idade+Batch+Idade ² +Veloci	5	Value	1559.6
Linear	Intercepto+Weight+Ent_ext+te+Umid_litter	5	Value	1559.8
Linear	Intercepto+Weight+Weight ² +he	4	Value	1560.3
Linear	Intercepto+Weight+Ent_interna+te+Umid_litter	5	Value	1560.6
Linear	Intercepto+Weight+Weight ² +umid	4	Value	1560.8
Linear	Intercepto+broiler_house+Idade+Batch+Ent_interna	5	Value	1558.9
Linear	Intercepto+broiler_house+Idade+Batch+Ent_interna+ Idade ²	6	Value	1559.2
Linear	Intercepto+Weight+he+temp	4	Value	1562.6
Linear	Intercepto+broiler_house+Weight+Weight ²	4	Value	1561.5
Linear	Intercepto+Weight+te	3	Value	1563.7
Linear	Intercepto+Idade+Veloci+Umid_litter	4	Value	1563.8
Linear	Intercepto+Weight+Batch+umid	4	Value	1563.8
Linear	Intercepto+Weight+Batch+he	4	Value	1563.8
Linear	Intercepto+broiler_house+Weight+C_litter	4	Value	1561.9
Linear	Intercepto+broiler_house+Weight+te	4	Value	1562.0
Linear	Intercepto+Idade+Veloci+Ent_ext	4	Value	1565.0
Linear	Intercepto+Weight+Weight ²	3	Value	1565.1

Appendix A. Linear mixed models tested to identify the variables that describe CO₂ emission fluxes.

(continued)

Linear	Intercepto+broiler_house+Weight+temp	4	Value	1563.4
Linear	Intercepto+broiler_house+Idade+C_litter	4	Value	1563.7
Linear	Intercepto+Weight+Weight ² +Ent_ext	4	Value	1566.5
Linear	Intercepto+broiler_house+Weight+Batch	4	Value	1564.5
Linear	Intercepto+Weight+temp	3	Value	1566.6
Linear	Intercepto+Idade+Veloci+he	4	Value	1566.8
Linear	Intercepto+broiler_house+Weight+Veloci	4	Value	1565.4
Linear	Intercepto+Idade+Veloci+umid	4	Value	1567.5
Linear	Intercepto+broiler_house+Weight+Umid_litter	4	Value	1565.6
Linear	Intercepto+Weight+VELOCI	3	Value	1568.2
Linear	Intercepto+Weight+Batch1	3	Value	1568.3
Linear	Intercepto+Weight+Batch	3	Value	1568.4
Linear	Intercepto+broiler_house+Idade+te	4	Value	1567.1
Linear	Intercepto+Weight+Umid_litter	3	Value	1569.1
Linear	Intercepto+idade+te	3	Value	1569.5
Linear	Intercepto+broiler_house+Idade+Batch	4	Value	1567.9
Linear	Intercepto+broiler_house+Idade+Veloci	4	Value	1568.7
Linear	Intercepto+Weight+Ent_ext+te	4	Value	1570.8
Linear	Intercepto+Weight+Ent_ext+temp	4	Value	1571.2
Linear	Intercepto+Weight+Weight ² +Ent_interna	4	Value	1571.6
Linear	Intercepto+Idade+Veloci+Veloci	4	Value	1571.9
Linear	Intercepto+idade+VELOCI	3	Value	1571.9
Linear	Intercepto+broiler_house+Idade+temp	4	Value	1570.0
Linear	Intercepto+idade+Batch1	3	Value	1572.0
Linear	Intercepto+Weight+Ent_interna+te	4	Value	1572.1
Linear	Intercepto+Idade+Batch+Idade ²	4	Value	1572.2
Linear	Intercepto+idade+Batch	3	Value	1572.4
Linear	Intercepto+broiler_house+Weight+he	4	Value	1571.5
Linear	Intercepto+broiler_house+Weight+umid	4	Value	1571.7
Linear	Intercepto+idade+temp	3	Value	1573.7
Linear	Intercepto+broiler_house+Idade+Umid_litter	4	Value	1572.1
Linear	Intercepto+Weight+Ent_interna+temp	4	Value	1574.6
Linear	Intercepto+Idade+Veloci+Ent_interna	4	Value	1575.5
Linear	Intercepto+umid	3	Value	1575.5
Linear	Intercepto+idade+Umid_litter	3	Value	1575.9
Linear	Intercepto+Idade+Batch+Ent_interna+ Idade ²	5	Value	1576.1
Linear	Intercepto+broiler_house+Idade+he	4	Value	1575.2

Appendix A. Linear mixed models tested to identify the variables that describe CO₂ emission fluxes.

(conclusion)

Linear	Intercepto+broiler_house+Weight	3	Value	1576.4
Linear	Intercepto+idade+umid	3	Value	1579.6
Linear	Intercepto+Weight+Ent_ext	3	Value	1580.0
Linear	Intercepto+Weight	2	Value	1580.1
Linear	Intercepto+broiler_house+Weight+Ent_ext	4	Value	1579.1
Linear	Intercepto+broiler_house+Idade	3	Value	1579.8
Linear	Intercepto+broiler_house+Idade+Idade ²	4	Value	1580.0
Linear	Intercepto+Idade	2	Value	1584.0
Linear	Intercepto+Idade+Idade ²	3	Value	1584.2
Linear	Intercepto+idade+Ent_ext	3	Value	1584.6
Linear	Intercepto+broiler_house+Weight+Ent_interna	4	Value	1582.7
Linear	Intercepto+Weight+Ent_interna	3	Value	1585.3
Linear	Intercepto+broiler_house+Idade+Ent_interna	4	Value	1586.9
Linear	Intercepto+idade+Ent_interna	3	Value	1590.1
Linear	Intercepto+VELOC	2	Value	1620.7
Linear	Intercepto+broiler_house+Veloci	3	Value	1620.7
Linear	Intercepto+broiler_house+temp	3	Value	1619.6
Linear	Intercepto+temp	2	Value	1619.6
Linear	Intercepto+Umid_litter	2	Value	1629.8
Linear	Intercepto+broiler_house+Umid_litter	3	Value	1629.8
Linear	Intercepto+broiler_house+C_litter	3	Value	1631.1
Linear	Intercepto+broiler_house+umid	3	Value	1647.8
Linear	Intercepto+umid	2	Value	1647.8
Linear	Intercepto+broiler_house+te	3	Value	1651.2
Linear	Intercepto+te	2	Value	1651.2
Linear	Intercepto+broiler_house+Batch1	3	Value	1655.6
Linear	Intercepto+Batch1	2	Value	1658.3
Linear	Intercepto+broiler_house+Batch	3	Value	1658.7
Linear	Intercepto+Batch	2	Value	1658.7
Linear	Intercepto+broiler_house+he	3	Value	1661.9
Linear	Intercepto+broiler_house+Ent_interna	3	Value	1668.8
Linear	Intercepto+Ent_interna	2	Value	1668.8
Linear	Intercepto	1	Value	1670.6
Linear	Intercepto+broiler_house	2	Value	1670.6
Linear	Intercepto+Ent_ext	2	Value	1672.7

Appendix B. Linear mixed models tested to identify the variables that describe NH₃ emission fluxes

(continued)

Type	Variables	N_Parameters	_NAM E_	_2_Res_Log_Likeliho od
Linear	Intercepto+Weight+Weight ² +veloci+N_litter_g_kg+N_litter_g_kg ²	6	Value	779.1
Linear	Intercepto+broiler_house+Weight+batch+turno+Weight ²	6	Value	778.9
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Veloci+turno	6	Value	782.7
Linear	Intercepto+Weight+Weight ² +Batch+te+turno	6	Value	783.7
Linear	Intercepto+Weight+Weight ² +Batch+te+umid	6	Value	784.7
Linear	Intercepto+broiler_house+Weight+Batch+Weight ² +veloci	6	Value	783.2
Linear	Intercepto+broiler_house+Weight+batch+veloci+Weight ²	6	Value	783.2
Linear	Intercepto+Weight+Weight ² +C_litter+turno	5	Value	785.5
Linear	Intercepto+Weight+Weight ² +Batch+te+Veloci	6	Value	786.6
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Veloci+Umid_litter	6	Value	787.6
Linear	Intercepto+Weight+Weight ² +Batch+turno	5	Value	787.6
Linear	Intercepto+Weight+Weight ² +Batch+te+he	6	Value	787.8
Linear	Intercepto+Weight+Weight ² +Batch+te+N_litter_g_kg	6	Value	788.1
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+turno	5	Value	788.2
Linear	Intercepto+Weight+Weight ² +Batch+te+Umid_litter	6	Value	788.4
Linear	Intercepto+broiler_house+Weight+Batch+Weight ² +te	6	Value	786.5
Linear	Intercepto+broiler_house+Weight+batch+te+ Weight ²	6	Value	786.5
Linear	Intercepto+Weight+Weight ² +Batch+te+Broiler_house	6	Value	786.5
Linear	Intercepto+broiler_house+Weight+Batch+Weight ² +temp	6	Value	787.0
Linear	Intercepto+Weight+Weight ² +Batch+te+temp	6	Value	789.0
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Veloci+umid	6	Value	789.4
Linear	Intercepto+Weight+Weight ² +Batch+te	5	Value	790.2
Linear	Intercepto+Weight+batch+te+ Weight ²	5	Value	790.2
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Veloci+temp	6	Value	790.7

Appendix B. Linear mixed models tested to identify the variables that describe NH₃ emission fluxes

(continued)

Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Veloci+te	6	Value	791.4
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Veloci	5	Value	791.7
Linear	Intercepto+Weight+Weight ² +C_litter+temp	5	Value	791.7
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Veloci+Broiler_house	6	Value	790.5
Linear	Intercepto+Weight+Weight ² +C_litter+te	5	Value	792.9
Linear	Intercepto+Weight+Weight ² +C_litter+Veloci	5	Value	793.4
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Veloci+he	6	Value	793.7
Linear	Intercepto+Weight+Weight ² +Batch+temp	5	Value	793.7
Linear	Intercepto+Weight+Batch+Weight ² +Veloci	5	Value	793.7
Linear	Intercepto+Weight+Weight ² +Batch+Veloci	5	Value	793.7
Linear	Intercepto+broiler_house+Weight+Batch+Ent_interna+Weight ²	6	Value	791.8
Linear	Intercepto+broiler_house+Weight+Batch+Weight ² +Ent_interna	6	Value	791.8
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Batch	5	Value	794.6
Linear	Intercepto+broiler_house+Weight+Batch+Weight ² +Umid_litter	6	Value	792.7
Linear	Intercepto+Weight+Weight ² +Batch+C_litter	5	Value	795.2
Linear	Intercepto+broiler_house+Weight+Batch+Weight ²	5	Value	793.3
Linear	Intercepto+Weight+Weight ² +Rel_C_N+turno	5	Value	796.1
Linear	Intercepto+Weight+Weight ² +Rel_C_N+Batch	5	Value	796.8
Linear	Intercepto+Weight+Weight ² +Rel_C_N+Veloci+te	6	Value	796.9
Linear	Intercepto+broiler_house+Weight+Batch+Ent_ext+Weight ²	6	Value	795.2
Linear	Intercepto+Weight+Weight ² +Batch+te+Ent_interna	6	Value	797.4
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+te	5	Value	797.9
Linear	Intercepto+Weight+Batch+Ent_ext+Weight ²	5	Value	798.3
Linear	Intercepto+Weight+Weight ² +Batch+Ent_ext	5	Value	798.3
Linear	Intercepto+Weight+Weight ² +Batch+te+Ent_ext	6	Value	798.4
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+temp	5	Value	798.7
Linear	Intercepto+Weight+Batch+Ent_interna+Weight ²	5	Value	799.2
Linear	Intercepto+Weight+Weight ² +Batch+Ent_interna	5	Value	799.2
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Umid_litter	5	Value	799.2
Linear	Intercepto+Weight+Weight ² +Batch+Umid_litter	5	Value	799.2

Appendix B. Linear mixed models tested to identify the variables that describe NH₃ emission fluxes

(continued)

Linear	Intercepto+Weight+Weight ² +C_litter+Ent_interna	5	Value	799.5
Linear	Intercepto+Weight+Weight ² +C_litter+Broiler_house	5	Value	799.5
Linear	Intercepto+Weight+Weight ² +C_litter	4	Value	799.5
Linear	Intercepto+Weight+Weight ² +Rel_C_N+Veloci	5	Value	799.8
Linear	Intercepto+Weight+Weight ² +turno	4	Value	799.9
Linear	Intercepto+Weight+Batch+Weight ²	4	Value	800.1
Linear	Intercepto+Weight+Weight ² +C_litter+umid	5	Value	800.1
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Veloci+Ent_interna	6	Value	800.3
Linear	Intercepto+Weight+Weight ² +Rel_C_N+te	5	Value	801.4
Linear	Intercepto+Weight+Weight ² +C_litter+he	5	Value	803.0
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Broiler_house	5	Value	801.2
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Veloci+Ent_ext	6	Value	803.5
Linear	Intercepto+Weight+Weight ² +Batch+he	5	Value	803.6
Linear	Intercepto+Weight+Weight ² +te	4	Value	804.3
Linear	Intercepto+broiler_house+Idade+batch+te+veloci+turno	7	Value	802.6
Linear	Intercepto+Weight+Weight ² +Veloci	4	Value	804.7
Linear	Intercepto+Weight+Weight ² +Rel_C_N+temp	5	Value	804.9
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+he	5	Value	805.0
Linear	Intercepto+broiler_house+Idade+batch+turno+Veloci	6	Value	803.0
Linear	Intercepto+Weight+Weight ² +C_litter+Ent_ext	5	Value	805.0
Linear	Intercepto+Weight+Weight ² +N_litter_g_kg+Ent_interna	5	Value	806.0
Linear	Intercepto+broiler_house+Idade+batch+turno+temp	6	Value	804.5
Linear	Intercepto+Weight+Weight ² +Rel_C_N+Umid_litter	5	Value	806.6
Linear	Intercepto+broiler_house+Weight+batch+turno+temp	6	Value	805.4
Linear	Intercepto+broiler_house+Idade+batch+turno+Umid_litter	6	Value	805.7
Linear	Intercepto+broiler_house+Weight+batch+turno+Umid_litter	6	Value	806.0
Linear	Intercepto+Weight+Weight ² +temp	4	Value	808.1
Linear	Intercepto+Weight+Weight ² +Rel_C_N+umid	5	Value	808.8

Appendix B. Linear mixed models tested to identify the variables that describe NH₃ emission fluxes

(continued)

Linear	Intercepto+broiler_house+Idade+batch+te+ turno	6	Value	808.2
Linear	Intercepto+Weight+Weight ² +Rel_C_N+Broiler_house	5	Value	808.4
Linear	Intercepto+broiler_house+Idade+batch+te+Veloci	6	Value	808.7
Linear	Intercepto+Weight+Weight ² +Umid_litter	4	Value	811.0
Linear	Intercepto+Weight+veloci+te+C_litter+Umid_litter	6	Value	811.1
Linear	Intercepto+broiler_house+Idade+batch+turno+Idade ²	6	Value	809.3
Linear	Intercepto+broiler_house+Idade+batch+te+ Umid_litter	6	Value	809.5
Linear	Intercepto+Weight+Weight ² +Rel_C_N+he	5	Value	811.6
Linear	Intercepto+broiler_house+Idade+Batch+turno+Idade*t urno	6	Value	809.7
Linear	Intercepto+broiler_house+Idade+Batch+Veloci	5	Value	810.2
Linear	Intercepto+Weight+Weight ²	3	Value	812.2
Linear	Intercepto+broiler_house+Idade+Batch+Ent_interna+ turno	6	Value	810.4
Linear	Intercepto+broiler_house+Idade+batch+te+ temp	6	Value	810.7
Linear	Intercepto+broiler_house+Idade+Batch+turno	5	Value	810.7
Linear	Intercepto+broiler_house+Weight+batch+te+ temp	6	Value	810.8
Linear	Intercepto+broiler_house+Weight+Batch+temp	5	Value	811.0
Linear	Intercepto+Weight+Weight ² +umid	4	Value	813.2
Linear	Intercepto+Weight+N_litter_g_kg+te+Umid_litter	5	Value	813.3
Linear	Intercepto+broiler_house+Idade+batch+te+he	6	Value	811.4
Linear	Intercepto+broiler_house+Idade+Batch+temp	5	Value	811.5
Linear	Intercepto+Weight+turno+te+Umid_litter	5	Value	813.8
Linear	Intercepto+broiler_house+Weight+batch+te+veloci+W eight*te	7	Value	811.8
Linear	Intercepto+broiler_house+Idade+batch+te+ umid	6	Value	811.8
Linear	Intercepto+Weight+C_litter+temp+N_litter_g_kg	5	Value	813.9
Linear	Intercepto+Weight+veloci+te+N_litter_g_kg+N_litter_ g_kg ²	6	Value	813.9
Linear	Intercepto+broiler_house+Idade+batch+veloci+Idade ²	6	Value	812.0
Linear	Intercepto+broiler_house+Weight+Weight ²	4	Value	812.2
Linear	Intercepto+broiler_house+Weight+batch+turno+Veloci	6	Value	812.6
Linear	Intercepto+broiler_house+Weight+Batch+turno+Weigh t*turno	6	Value	812.7

Appendix B. Linear mixed models tested to identify the variables that describe NH₃ emission fluxes

(continued)

Linear	Intercepto+Weight+Weight ² +he	4	Value	815.1
Linear	Intercepto+Weight+Weight ² +Rel_C_N+Ent_ext	5	Value	815.6
Linear	Intercepto+Weight+C_litter+temp	4	Value	815.6
Linear	Intercepto+Weight+turno+temp+N_litter_g_kg	5	Value	815.9
Linear	Intercepto+Weight+Batch+temp	4	Value	816.0
Linear	Intercepto+broiler_house+Idade+Batch+Ent_interna+Veloci	6	Value	814.0
Linear	Intercepto+broiler_house+Weight+batch+te+ turno	6	Value	814.1
Linear	Intercepto+Weight+Weight ² +Rel_C_N+Ent_interna	5	Value	816.1
Linear	Intercepto+Weight+veloci+te+C_litter+turno	6	Value	816.1
Linear	Intercepto+broiler_house+Idade+batch+te	5	Value	814.6
Linear	Intercepto+Weight+veloci+temp+N_litter_g_kg	5	Value	816.9
Linear	Intercepto+Weight+veloci+te+C_litter+batch	6	Value	817.1
Linear	Intercepto+broiler_house+Idade+batch+te+ Idade ²	6	Value	815.1
Linear	Intercepto+broiler_house+Weight+batch+te+Veloci	6	Value	815.4
Linear	Intercepto+broiler_house+Weight+Batch+Ent_interna+Umid_litter	6	Value	815.8
Linear	Intercepto+broiler_house+Idade+Batch+Ent_interna+Umid_litter	6	Value	816.1
Linear	Intercepto+broiler_house+Idade+batch+te+C_litter	6	Value	816.3
Linear	Intercepto+broiler_house+Weight+Batch+Ent_interna+turno	6	Value	816.5
Linear	Intercepto+Idade+batch+te+ Idade ²	5	Value	818.5
Linear	Intercepto+Weight+Weight ² +Ent_ext	4	Value	818.8
Linear	Intercepto+broiler_house+Weight+batch+te+he	6	Value	817.2
Linear	Intercepto+Weight+Umid_litter+te	4	Value	819.2
Linear	Intercepto+broiler_house+Idade+Batch+Ent_interna+veloci+Batch*Idade	7	Value	817.4
Linear	Intercepto+broiler_house+Idade+Batch+Ent_interna+Temp	6	Value	817.5
Linear	Intercepto+Weight+Weight ² +Ent_interna	4	Value	819.7
Linear	Intercepto+Weight+veloci+te+C_litter+N_litter_g_kg	6	Value	820.1
Linear	Intercepto+Weight+turno+te+C_litter	5	Value	820.1
Linear	Intercepto+broiler_house+Weight+Batch+Umid_litter	5	Value	818.2
Linear	Intercepto+broiler_house+Idade+Batch+Umid_litter	5	Value	818.2
Linear	Intercepto+Idade+Veloci+batch	4	Value	820.3
Linear	Intercepto+broiler_house+Weight+Batch+turno	5	Value	818.4

Appendix B. Linear mixed models tested to identify the variables that describe NH₃ emission fluxes

(continued)

Linear	Intercepto+Idade+Veloci+turno	4	Value	820.9
Linear	Intercepto+Weight+Umid_litter+temp	4	Value	820.9
Linear	Intercepto+broiler_house+Idade+Batch+Ent_interna+Idade ²	6	Value	819.2
Linear	Intercepto+Weight+batch+te	4	Value	821.2
Linear	Intercepto+broiler_house+Idade+Batch+Ent_interna	5	Value	819.3
Linear	Intercepto+Weight+he+te+Umid_litter	5	Value	821.3
Linear	Intercepto+Weight+turno+te+N_litter_g_kg	5	Value	821.4
Linear	Intercepto+broiler_house+Weight+batch+turno+umid	6	Value	819.4
Linear	Intercepto+broiler_house+Idade+Batch+Ent_interna+C_litter	6	Value	819.5
Linear	Intercepto+broiler_house+Weight+Batch+Ent_interna+Temp	6	Value	819.5
Linear	Intercepto+broiler_house+Weight+batch+te	5	Value	819.6
Linear	Intercepto+broiler_house+Weight+Batch+Ent_ext+Umid_litter	6	Value	819.8
Linear	Intercepto+broiler_house+Weight+Batch+Veloci	5	Value	820.0
Linear	Intercepto+Idade+Batch+Idade ² +Veloci	5	Value	822.0
Linear	Intercepto+Weight+veloci+te+C_litter+he	6	Value	822.1
Linear	Intercepto+Weight+veloci+te+C_litter+broiler_house	6	Value	822.1
Linear	Intercepto+Weight+veloci+te+C_litter	5	Value	822.1
Linear	Intercepto+Idade+Veloci+C_litter	4	Value	822.2
Linear	Intercepto+broiler_house+Weight+batch+te+ umid	6	Value	820.2
Linear	Intercepto+Weight+N_litter_g_kg+temp	4	Value	822.3
Linear	Intercepto+Weight+Umid_litter+temp+N_litter_g_kg	5	Value	822.3
Linear	Intercepto+Weight+turno+temp	4	Value	822.4
Linear	Intercepto+broiler_house+Weight+Batch+Ent_interna+Veloci	6	Value	820.5
Linear	Intercepto+Weight+veloci+te+N_litter_g_kg	5	Value	822.6
Linear	Intercepto+Weight+he+temp+N_litter_g_kg	5	Value	822.8
Linear	Intercepto+broiler_house+Weight+batch+te+C_litter	6	Value	820.8
Linear	Intercepto+Weight+veloci+te+temp	5	Value	822.9
Linear	Intercepto+Weight+Batch+Umid_litter	4	Value	822.9

Appendix B. Linear mixed models tested to identify the variables that describe NH₃ emission fluxes

(continued)

Linear	Intercepto+Idade+Veloci+Umid_litter	4	Value	823.1
Linear	Intercepto+broiler_house+Idade+Batch+Ent_interna+umid	6	Value	821.4
Linear	Intercepto+Weight+Batch+turno	4	Value	823.5
Linear	Intercepto+Idade+Veloci+te	4	Value	823.6
Linear	Intercepto+broiler_house+Idade+Batch+Ent_interna+he	6	Value	821.8
Linear	Intercepto+Weight+veloci+te+Rel_C_N	5	Value	823.8
Linear	Intercepto+Idade+Veloci+temp	4	Value	823.9
Linear	Intercepto+Weight+veloci+temp	4	Value	823.9
Linear	Intercepto+broiler_house+Idade+Batch+Idade ²	5	Value	821.9
Linear	Intercepto+Weight+C_litter+te+N_litter_g_kg	5	Value	824.2
Linear	Intercepto+Weight+N_litter_g_kg+te+C_litter	5	Value	824.2
Linear	Intercepto+broiler_house+Weight+Batch+Ent_ext+Temp	6	Value	822.4
Linear	Intercepto+broiler_house+Idade+Batch+umid	5	Value	822.6
Linear	Intercepto+broiler_house+Weight+Batch+Ent_ext+turno	6	Value	822.7
Linear	Intercepto+broiler_house+Idade+batch1	4	Value	822.8
Linear	Intercepto+Weight+he+te+C_litter	5	Value	825.9
Linear	Intercepto+Weight+C_litter+te	4	Value	826.0
Linear	Intercepto+Idade+Batch+Ent_interna+ Idade ²	5	Value	826.0
Linear	Intercepto+Weight+turno+te	4	Value	826.0
Linear	Intercepto+broiler_house+Weight+Batch+Ent_interna+C_litter	6	Value	824.0
Linear	Intercepto+broiler_house+Weight+Batch+Ent_interna+umid	6	Value	824.1
Linear	Intercepto+broiler_house+Idade+batch+C_litter	5	Value	824.3
Linear	Intercepto+broiler_house+Weight+Batch+Ent_interna	5	Value	824.5
Linear	Intercepto+idade+turno	3	Value	826.6
Linear	Intercepto+Weight+Batch+Veloci	4	Value	826.9
Linear	Intercepto+Weight+veloci+te+C_litter+Ent_interna	6	Value	827.0
Linear	Intercepto+Weight+he+te+N_litter_g_kg	5	Value	827.2
Linear	Intercepto+Weight+veloci+te	4	Value	827.2
Linear	Intercepto+Weight+N_litter_g_kg+te	4	Value	827.6

Appendix B. Linear mixed models tested to identify the variables that describe NH₃ emission fluxes

(continued)

Linear	Intercepto+Weight+Umid_litter+te+N_litter_g_kg	5	Value	827.6
Linear	Intercepto+broiler_house+Weight+Batch+Ent_ext+Veloci	6	Value	825.7
Linear	Intercepto+broiler_house+Idade+batch+he	5	Value	825.9
Linear	Intercepto+Idade+Veloci+Veloci	4	Value	828.2
Linear	Intercepto+idade+VELOCI	3	Value	828.2
Linear	Intercepto+Weight+veloci+te+he	5	Value	828.2
Linear	Intercepto+idade+te	3	Value	828.2
Linear	Intercepto+broiler_house+Weight+Batch+Ent_interna+he	6	Value	826.2
Linear	Intercepto+Idade+Batch+Idade ²	4	Value	828.3
Linear	Intercepto+Weight+temp	3	Value	828.4
Linear	Intercepto+broiler_house+Idade+turno	4	Value	826.4
Linear	Intercepto+idade+batch1	3	Value	828.4
Linear	Intercepto+Weight+veloci+te+umid	5	Value	828.8
Linear	Intercepto+broiler_house+Idade+Veloci	4	Value	827.0
Linear	Intercepto+idade+temp	3	Value	829.5
Linear	Intercepto+broiler_house+Weight+temp	4	Value	827.7
Linear	Intercepto+Idade+Veloci+umid	4	Value	829.7
Linear	Intercepto+broiler_house+Idade+te	4	Value	827.7
Linear	Intercepto+broiler_house+Idade+C_litter	4	Value	830.6
Linear	Intercepto+broiler_house+Idade+temp	4	Value	828.8
Linear	Intercepto+Weight+he+temp	4	Value	830.9
Linear	Intercepto+Weight+Ent_interna+te+C_litter	5	Value	831.0
Linear	Intercepto+Weight+te	3	Value	831.3
Linear	Intercepto+Idade+Veloci+he	4	Value	831.4
Linear	Intercepto+broiler_house+Weight+batch1	4	Value	829.4
Linear	Intercepto+Weight+Umid_litter	3	Value	831.6
Linear	Intercepto+broiler_house+Weight+Umid_litter	4	Value	831.6
Linear	Intercepto+broiler_house+Weight+Batch+Ent_ext	5	Value	829.6
Linear	Intercepto+Weight+turno	3	Value	831.6
Linear	Intercepto+Weight+Ent_interna+te+Umid_litter	5	Value	831.8
Linear	Intercepto+Weight+batch+C_litter	4	Value	831.9
Linear	Intercepto+Weight+he+te	4	Value	832.2
Linear	Intercepto+Weight+Ent_interna+temp+N_litter_g_kg	5	Value	832.2
Linear	Intercepto+broiler_house+Weight+batch+C_litter	5	Value	830.5
Linear	Intercepto+idade+Umid_litter	3	Value	832.5
Linear	Intercepto+broiler_house+Idade+Umid_litter	4	Value	832.5

Appendix B. Linear mixed models tested to identify the variables that describe NH₃ emission fluxes

(continued)

Linear	Intercepto+broiler_house+Weight+Batch+Ent_ext+C_litter	6	Value	830.8
Linear	Intercepto+broiler_house+Weight+te	4	Value	831.1
Linear	Intercepto+broiler_house+Weight+Batch+Ent_ext+umid	6	Value	831.5
Linear	Intercepto+Weight+batch1	3	Value	833.5
Linear	Intercepto+broiler_house+Weight+turno	4	Value	831.6
Linear	Intercepto+Weight+Ent_ext+te+Umid_litter	5	Value	833.7
Linear	Intercepto+broiler_house+Weight+Batch+umid	5	Value	831.7
Linear	Intercepto+Weight+veloci+te+C_litter+Ent_ext	6	Value	834.1
Linear	Intercepto+Weight+VELOCI	3	Value	834.2
Linear	Intercepto+broiler_house+Weight+Batch+Ent_ext+he	6	Value	832.5
Linear	Intercepto+broiler_house+Weight+batch+he	5	Value	832.6
Linear	Intercepto+Weight+Ent_interna+te+N_litter_g_kg	5	Value	834.7
Linear	Intercepto+Weight+Ent_ext+temp+N_litter_g_kg	5	Value	834.9
Linear	Intercepto+broiler_house+Weight+C_litter	4	Value	835.6
Linear	Intercepto+broiler_house+Weight+Veloci	4	Value	833.9
Linear	Intercepto+Weight+Batch+umid	4	Value	836.0
Linear	Intercepto+Weight+batch+he	4	Value	836.6
Linear	Intercepto+Idade+Veloci+Ent_ext	4	Value	837.0
Linear	Intercepto+Idade+Veloci+Ent_interna	4	Value	837.0
Linear	Intercepto+Idade	2	Value	837.3
Linear	Intercepto+Weight+Ent_ext+te+C_litter	5	Value	838.0
Linear	Intercepto+Weight+veloci+te+Ent_interna	5	Value	838.1
Linear	Intercepto+Idade+Idade ²	3	Value	838.2
Linear	Intercepto+broiler_house+Idade+umid	4	Value	838.9
Linear	Intercepto+idade+umid	3	Value	838.9
Linear	Intercepto+Weight+Ent_ext+te+N_litter_g_kg	5	Value	839.0
Linear	Intercepto+broiler_house+Idade	3	Value	837.3
Linear	Intercepto+broiler_house+Idade+Idade ²	4	Value	838.1
Linear	Intercepto+Weight+veloci+te+Ent_ext	5	Value	840.5
Linear	Intercepto+Weight+Ent_interna+temp	4	Value	840.7
Linear	Intercepto+Weight+Ent_ext+temp	4	Value	840.9
Linear	Intercepto+idade+Ent_ext	3	Value	841.5
Linear	Intercepto+Weight	2	Value	841.8
Linear	Intercepto+broiler_house+Weight	3	Value	841.8
Linear	Intercepto+Weight+Ent_interna+te	4	Value	842.0
Linear	Intercepto+idade+Ent_interna	3	Value	842.2

Appendix B. Linear mixed models tested to identify the variables that describe NH₃ emission fluxes

(conclusion)

Linear	Intercepto+broiler_house+Weight+he	4	Value	844.4
Linear	Intercepto+Weight+Ent_ext+te	4	Value	844.4
Linear	Intercepto+broiler_house+Weight+umid	4	Value	844.5
Linear	Intercepto+umid	3	Value	844.5
Linear	Intercepto+broiler_house+Weight+Ent_interna	4	Value	845.3
Linear	Intercepto+Weight+Ent_interna	3	Value	845.3
Linear	Intercepto+broiler_house+Weight+Ent_ext	4	Value	846.2
Linear	Intercepto+Weight+Ent_ext	3	Value	846.2
Linear	Intercepto+broiler_house+temp	3	Value	850.8
Linear	Intercepto+temp	2	Value	850.8
Linear	Intercepto+Umid_litter	2	Value	862.4
Linear	Intercepto+broiler_house+Umid_litter	3	Value	862.4
Linear	Intercepto+broiler_house+C_litter	3	Value	873.7
Linear	Intercepto+VELOCI	2	Value	884.5
Linear	Intercepto+broiler_house+Veloci	3	Value	884.5
Linear	Intercepto+broiler_house+te	3	Value	886.1
Linear	Intercepto+te	2	Value	886.1
Linear	Intercepto+batch1	2	Value	893.5
Linear	Intercepto+broiler_house+turno	3	Value	893.9
Linear	Intercepto+turno	2	Value	893.9
Linear	Intercepto+broiler_house+batch1	3	Value	893.0
Linear	Intercepto+broiler_house+umid	3	Value	894.1
Linear	Intercepto+umid	2	Value	894.1
Linear	Intercepto+Ent_interna	2	Value	897.9
Linear	Intercepto+broiler_house+Ent_interna	3	Value	897.8
Linear	Intercepto+broiler_house	2	Value	901.4
Linear	Intercepto	1	Value	901.4
Linear	Intercepto+broiler_house+he	3	Value	901.2
Linear	Intercepto+Ent_ext	2	Value	908.0