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Review

Ammonia Emission in Poultry Facilities: A Review for Tropical Climate Areas

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Abstract: Brazil is the largest broiler meat exporter in the world. This important economic activity generates income in different branches of the production chain. However, the decomposition of residues incorporated in the poultry litter generates several gases, among them ammonia. When emitted from the litter to the air, ammonia can cause several damages to animals and man, in addition to being able to convert into a greenhouse gas. Thus, the aim of this article was to carry out a review of the ammonia emission factors in the production of broilers, the methodologies for measuring, and the inventories of emissions already carried out in several countries. The main chemical processes for generating ammonia in poultry litter have been introduced and some practices that can contribute to the reduction of ammonia emissions have been provided. The PMU, Portable Monitoring Unit, and the SMDAE, Saraz Method for Determination of Ammonia Emissions, with the required adaptations, are methodologies that can be used to quantify the ammonia emissions in hybrid facilities with a natural and artificial ventilation system. An ammonia emission inventory can contribute to the control and monitoring of pollutant emissions and is an important step towards adopting emission reductions. However, quantifying the uncertainties about ammonia emission inventories is still a challenge to be overcome.

Keywords: air quality; livestock production; poultry housing; waste management

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1. Introduction

It is estimated that the world population will reach 9.3 billion people in 2050 [1]. With the increase in population, an increase in food production is demanded. To meet this demand, the modern livestock industry has been showing a tendency to produce animals in feedlots. In confinements, fully closed, air-conditioned, and fully open installations with naturally ventilated can be used, as well as hybrid installations that work open or closed using artificial thermal conditioning systems, depending on local climatic conditions. The production of broilers stands out among other meat production systems for presenting low cost and short production cycles [2,3]. The USA is today the largest producer of chicken meat in the world, followed by China and Brazil [4].

In 2020, Brazilian chicken meat production grew around 4% compared to 2019. With 4.23 million tons exported, Brazil once again established itself as the world's largest chicken meat exporter, a position it has occupied since 2004. The annual consumption of this animal protein in Brazil reached 45.27 kg per capita in 2020 [5]. In recent years, there have been significant technological advances in this sector, influenced by commercial and productive demands. These advances provided the supply of low-cost animal protein and the generation of jobs and income in the different branches of the national production chain [6,7].

In countries with a tropical climate, such as Brazil, poultry facilities are predominantly open or hybrid, that is, they can operate in an open or closed manner according to the thermal conditioning needs of the birds and the local climatic conditions. This typological trend is due to the advantages of the tropical climate, which allows the use of natural ventilation in aviaries reducing production costs [3,8]. In broiler production systems, poultry litter is used on the floor of the facility with the main function of incorporating the waste generated. However, the decomposition of waste in the litter generates several gases, the main one being ammonia (NH_3), because it is present in greater proportions than the other gases such as carbon monoxide (CO) and carbon dioxide (CO_2) [4]. In South America, most ammonia emissions come from agriculture, mainly from animal production due to the intensive production standards and density of animal housing adopted [9].

Ammonia can generate global effects when present in the atmosphere, and can contribute to the formation of nitrogen oxides, which are greenhouse gases [10]. In addition, ammonia in the atmosphere can contribute to the formation of acid rain, which can cause acidification and eutrophication of the soil and rivers [9,11,12].

Continuous exposure to high concentrations of ammonia is harmful to humans and animals. In humans, continuous exposure to ammonia causes respiratory problems [13], and eye irritation [14], which can lead to blindness [15]. In broilers, damages from continuous exposure are reported in the reduction of weight gain [16], problems related to irritation in the eyes, and the possibility of a higher incidence of diseases [17], which can even lead to death [11].

On the other hand, in the literature, studies are also reported showing that in vitro ammonia can even be beneficial to birds and that fish can be tolerant to ammonia and can even metabolize the ammonia present in water [18–20]. These studies confirm the fact that the exposure of embryonic cells to ammonia affects the expression of myostatin, which is a protein that is related to the production of muscle mass. Studies conducted with fish cells indicate that exposure to high concentrations of ammonia does not affect the myogenic response, which indicates that fish have ways of mediating ammonia toxicity [18]. In vitro studies with embryos from developing chickens suggest that the increase in serum ammonia concentration leads to a reduction in myostatin expression. Therefore, it is concluded that exposure to higher concentrations of ammonia in the embryonic stage can lead to improvements in muscle growth and meat production in poultry [19,20]. Given the biology of birds, it may be possible that broilers and layers will also show an adaptive response to facility environments with high ammonia content. However, the relatively short period of exposure and life span of broilers, which are slaughtered around 45 days of age, must also be considered in this development of the adaptive response to high concentrations of ammonia. Therefore, at least until then, awaiting further studies, it is important to consider most of the negative effects of high concentrations of ammonia in the facilities, caused in the first weeks of life, during the initial phase of chick growth.

However, given the environmental problems caused by the emission of gases in animal production, the countries of the European Union, with the objective of reducing ammonia emissions, have established policies that are currently used to monitor and control the maximum emissions of their states. The European Parliament and the Council of the European Union established Directive 2010/75/EU [21], which deals with aspects related to atmospheric emissions, including animal production facilities, with the aim of preventing, reducing, and even eliminating pollution.

In the Netherlands, the government encourages producers to reduce greenhouse gas emissions through, for example, the creation of a green seal that rewards producers who generate less greenhouse gases [22]. In countries such as the United Kingdom [23], Denmark [24], France [25], England [23], and the USA [26], inventories of annual ammonia emissions from animal production facilities are conducted. These inventories contribute to the monitoring and control of emissions of this gas in all productive sectors.

However, worldwide, there are still no methods to efficiently measure ammonia emission in open areas [22,27]. Despite the huge number of methods for measuring ammonia concentration, most are still expensive and have limitations in terms of measurement efficiency [28,29]. Another major challenge in determining emissions, especially in installations in tropical climate areas, which are predominantly open, is related to the difficulty in correctly measuring the ventilation rate, due to the complexity of the wind flow [8,22,27,30,31].

In Brazil, there are still no inventories of ammonia emissions. Information on actual annual emissions is still scarce. There are no standards that deal with the standardized methods that must be adopted in inspections. We are still restricted to labor standards related to the limits of workers' exposure to ammonia and to animal strain management manuals. There is a regulatory standard NR-15 [32] that determines the maximum concentration of ammonia to which the worker can be exposed during working hours. NR-15 sets a maximum exposure concentration of up to 20 ppm ammonia for 48 working hours per week. In the case of animal health and performance, specifically for poultry facilities, Brazilian producers only follow breeding manuals that present air quality guidelines and determine the minimum ventilation rate for air renewal inside the facility, in addition to the maximum concentration levels of gases. In the management manual for broilers of the Cobb line [33], among the air quality guidelines, a maximum limit of 10 ppm of ammonia in poultry facilities is established.

Thus, at the national level, in Brazil, there is still no environmental legislation that regulates the exposure of animals or people to ammonia concentrations or that imposes a limit on emissions into the atmosphere [34]. In addition, there is still no established standard method to measure ammonia emission rates in animal production facilities that have the constructive typology of tropical climate areas, so the studies on the methods that are used in the world and their application in facilities predominantly opens are so important. Thus, the objective is to carry out a review on ammonia emission in poultry facilities, list possible existing methods to measure ammonia emission applicable to poultry facilities in tropical conditions, and score existing ammonia emission inventories already developed in other countries.

1.1. Broiler Breeding Systems and Ammonia Generation

Broiler breeding is predominantly carried out in facilities with avian litter. This litter is a material that covers the floor of the installation, intended to receive animal waste and absorb moisture from the waste, in addition to other functions such as protection and insulation [35]. Its use in the production of broilers is considered a standard breeding method established in practically the whole world [2].

In Brazil, it is common to reuse the litter for several production cycles due to the unavailability of material that can be used as a substrate. It is possible to reuse poultry litter up to six times without significant damage to the productive performance of the animals. However, the more often the bed is reused, the greater the amount of accumulated waste, affecting the relationship between carbon and nitrogen and the potential for ammonia generation and emission. Thus, the practice of reuse should be carried out with caution as well as constant monitoring of ammonia concentrations inside the facility [36,37].

1.2. Ammonia Formation Process in Broiler Poultry

In the production of broilers, ammonia comes from two main sources. One of them is the hydrolysis of urea present in the urine of animals, carried out by the enzyme urease, a process called ureolysis [38]. However, urea degradation provides a lesser contribution to the formation of ammonia. The main source of ammonia in poultry is the degradation of nitrogen excreted as uric acid. Nitrogen in the form of uric acid excreted by birds accounts for about 50% of the proteins undigested by birds. The uric acid decomposition process occurs according to Equation (1), reported by Seedorf et al. (1998) and Ni et al. (1999) [39,40].

$$NH_4^+ + OH^- \text{->} NH_3 + H_2O \quad (1)$$

The process of formation of gaseous NH_3 is called volatilization, where ammonia in the gaseous phase is proportional to its form in liquid phase according to Henry's law (Equations (2) and (3)). This balance is shifted to the right as there is an increase in temperature, air velocity, and the contact area where the reaction occurs [11,38,40].

$$NH_4^+ (l) <-> NH_3 (l) + H^+ \quad (2)$$

$$NH_3 (l) <-> NH_3 (g) \quad (3)$$

The emissions of a gas can be of the transient, reactive, or constant type. Static emission occurs in pits with liquid waste storage. This type of emission has little influence on the emission rate itself. Reactive emission occurs through chemical reactions, such as enzymatic reactions, combustion reactions, or decomposition reactions, as with ammonia, where there is an enzymatic breakdown of uric acid. The transient emission occurs in short periods, usually caused by human action in situations of handling litter, feeding the animals, cleaning, and maintaining the facility [23].

1.3. Ways to Control and Reduce Ammonia Emissions in Broiler Poultry

With the practice of reusing avian litter, it is essential to adopt ways to control and reduce the emission of ammonia. When pH increases in poultry litter, under conditions of high moisture content, the process of transforming the NH_4^+ ion into ammonia is favored. However, the application of saline additives such as aluminum sulfate ($Al_2(SO_4)_3$) can reduce the pH of the poultry litter to values below 7. In addition to reducing the pH of the solution, this additive acts by reacting with the molecules of NH_3, forming the NH_4^+ ion; this in turn reacts with the sulfate ions, thus inhibiting the volatilization of NH_3 [37].

Medeiros et al. (2008) [41] evaluated the performance of several additives in containing ammonia volatilization and their effects under different moisture levels. Among the tested additives, copper sulfate ($CuSO_3$), aluminum sulfate ($Al_2(SO_4)_3$), and phosphate (PO_4^{3-}) were the ones that showed the highest efficiency in inhibiting volatilization. In this study, litter with high moisture content showed the lowest levels of volatilization due to the dissociative affinity of ammonia with water. However, a treatment based on increasing the water content of the litter would not be interesting, since one of the functions of the poultry litter is to absorb moisture from the manure.

A diet with lower protein content can also contribute significantly to the reduction of ammonia emission, since most of nitrogen consumed in the feed is eliminated in the poultry litter [42]. Inoue et al. (2012) [43] analyzed the relationship between diets with levels of protein and the concentration of NH_3 inside a facility for poultry. In this study, in the facilities where the birds received diets with high levels of protein and minimal supplementation of amino acids, higher concentrations of ammonia were detected. On the other hand, in the facilities where the birds received diets composed of ideal levels of protein, lower concentrations of NH_3 were detected. The recommended crude protein content in the diet for male broilers with medium performance ranges from 24.27% (1 to 7 days old) to 17.47% (43 to 46 days deity) [44].

1.4. Methodologies for Determining Ammonia Emissions

The main methods for measuring ammonia emissions have been developed in the countries of the Northern Hemisphere, where most poultry facilities are predominantly closed and insulated [22–24,26]. In tropical countries such as Brazil, animal production facilities are predominantly open, with natural ventilation systems, or hybrids, with the possibility of using natural or mechanized ventilation, and without adequate volume control indoor air. This makes it difficult to use the methods, considered standard, to measure ammonia emissions [45,46].

Although there are still no methods to effectively measure ammonia emission in open areas, in open animal production facilities or with large openings, regardless of the ventilation system, natural or artificial, the quantification of ammonia emission should preferably be carried out by the sum of the total mass of ammonia that flows from the interior to the exterior of the installation [11,22]. To overcome the problems related to the complex airflow in these open installations, an alternative is to calculate the ammonia mass flow by means of the product of the ventilation rate and the ammonia concentration. This approach requires some care, such as continuous and simultaneous measurements of the ventilation rate and the ammonia concentration inside and outside the installation, in order to correctly determine the ammonia flow [11,22].

There are several methods and sensors for measuring atmospheric ammonia concentration at ambient concentrations. Among the various ammonia detection techniques are methods based on electronics, electrochemistry, laser spectroscopy, surface acoustic wave, field effect transistors, and automated wet chemistry, optical, photoacoustic, and mass spectrometry [28,29]. A review article discusses ammonia detection techniques and the fundamental working principles of these techniques based on electronics, electrochemistry, tunable diode laser spectroscopy, surface acoustic wave and field effect transistors, together with various sensing materials. Among the frequently used ammonia detection methods, solid state detection techniques, including metal oxide and conductive polymer-based sensors, have advantages for being simple and economical to manufacture. Currently, it is common to incorporate carbon nanomaterials used to reduce the operating temperature. New and advanced laser sources have been increasingly used despite their limitations. In gas detection hybridization systems, transistors have been incorporated into modern circuitry [28].

In another comparative study among eleven atmospheric ammonia measurement systems [29], a high correlation was found between all tested methods, namely: wet chemistry systems, with offline analysis (annular rotary batch denuder, RBD) and with online analysis (Override Denuder sampling with online Analysis, AMANDA; AiR-Rmonia), Quantum Cascade Laser Absorption Spectrometers (dual large cell system; DUAL-QCLAS and compact system; c-QCLAS), photoacoustic spectrometers (WaSul-Flux; Nitrolux -100), cavity ring spectrometer (CRDS), chemical ionization mass spectrometer (CIMS), ion mobility spectrometer (IMS), and open-path Fourier transform infrared spectrometer (OP-FTIR). However, not all instruments tested in this research provided accurate measurements; while some methods are more effective under conditions of low concentrations, others respond better under conditions of high concentrations of ammonia [29]. Despite recent advances in the creation and adoption of new technologies and in the hybridization of materials and detection methods, reliable and continuous measurement of ammonia concentration remains a very challenging and costly issue [28,29].

Another important but still challenging parameter in determining ammonia emissions as a function of gas concentration and ventilation rate is the accurate determination of the facility's ventilation rate, especially in facilities with natural ventilation [27,31,47]. This is due to the lack of a reference measurement method for this condition and the errors and uncertainties associated with measurements in these facilities compared to mechanically ventilated facilities [27]. In addition to spatial and temporal variations in wind flow in open facilities. Therefore, the inclusion of errors and uncertainties when presenting emission values is essential. One way to reduce errors and uncertainties in the determination of ammonia emission in facilities with natural ventilation, which is the reality of most poultry facilities in tropical climate areas, is to use more accurate equipment to measure the ventilation rate and concentration of the gas and carry out a more comprehensive sampling with as many collection points as possible [27]. Combining air velocity measurements with wind flow pattern modeling techniques can also contribute to more accurate determinations in naturally ventilated facilities [31].

The passive flow methods are considered ideal for the conditions of naturally ventilated facilities, as they do not depend on the airflow to quantify the ammonia emission. However, they still require further development and validation against reference methods [31]. Therefore, these methods are appropriate for the typology adopted in Brazilian facilities, in addition to presenting advantages such as not needing an energy source for measurement [46], and having equipment that is easy to build, transport, and handle [22].

Among the existing passive flow methods, the SMDAE (Saraz Method for Determination of Ammonia Emissions) stands out, mainly at the research level, for presenting satisfactory precision in measurements [48,49].

In the method proposed by Osorio et al. (2014) [50], polyvinyl chloride (PVC) tubes of 30 cm in height and 20 cm in diameter are used, in addition to polyurethane foams, positioned internally in tubes containing acid solution (H_2SO_4) and glycerin ($C_3H_8O_3$), components that fix the ammonia gas by microdiffusion. The foams impregnated in an acid solution are positioned, one at 10 cm high with the function of retaining ammonia, and the other at 30 cm high, on top of the PVC tube, to avoid any contamination by external gases in the sample.

After the collection period, the foams are taken to the laboratory where the NH_3 concentration is quantified using the Kjedhal method [51]. Equation (4), established by Osorio et al. (2014) [50], determines the emission of ammonia by the SMDAE method.

$$\text{SMDAE} = \frac{\text{NH}_3}{\text{A} \times \text{t}} \tag{4}$$

where SMDAE is mass flow of NH_3 in grams per square meter per second, NH_3 is the mass of NH_3 in grams, A is the foam absorption area in square meter, and t is the foam exposure time.

The SMDAE method has as a limitation the high ammonia collection time, which can vary from two to four hours, making measurements time-consuming [30]. In addition, the need to use chemical components and laboratory analysis makes their use in the field unfeasible.

The methods of diffusion by active flow use some source of energy to detect some parameter. In these methods, the air is forced to pass at a point where it will be analyzed. After the analysis, the concentration of ammonia is determined [52]. This approach, in addition to providing accurate results, provides information about the dynamics of NH_3 emissions within the facility [22].

The Portable Monitoring Unit (PMU), according to Wheeler et al. (2013) [53], is a method of continuous monitoring that uses two electrochemical sensors to measure the concentration of NH_3 and a sensor to measure the concentration of CO_2. The CO_2 concentration is used to determine the air velocity, which is essential in calculating the ammonia emission rate.

The emission of ammonia determined by the PMU, by Equation (5), proposed by Li et al. (2008) [54], is based on the measurements of NH_3 electrochemical sensors and on the ventilation rate (Q), established by the CO_2 balance method, where the production of metabolic heat is related to the consumption of oxygen (O_2) and the production of carbon dioxide (CO_2) from birds in the breathing process.

$$[\text{ER}_{\text{NH3}}]\text{t} = \sum_{e=1}^{2} [\text{Q}]\text{t}\left([\text{C}_{\text{NH3}}]\text{e} - \frac{\rho\text{e}}{\rho\text{i}} [\text{C}_{\text{NH3}}]\text{i} \right) \times 10^{-6} \times \frac{\text{Wm}}{\text{Vm}} \times \frac{\text{Tstd}}{\text{Ta}} \times \frac{\text{Pa}}{\text{Pstd}} \tag{5}$$

where $[ER_{NH3}]t$ is ammonia emission rate of the facility in an instant t in grams per second, $[Q]t$ is average ventilation rate at time t at a given temperature and pressure in cubic meters per second, $[C_{NH3}]e$ is the average concentration of NH_3 in the external air in ppm_v, $[C_{NH3}]i$ is the average concentration of NH_3 in the air in ppm_v, ρ_e and ρ_i are specific mass of the indoor and outdoor air of the facility in kilograms dry air per cubic meters humid air, Wm is molar mass of NH_3 (17.031 g mol^{-1}), Vm is molar volume of NH_3 at standard temperature and pressure (24.14 L mol^{-1}), Tstd is standard temperature (273.12 K), Ta is absolute ambient air temperature in kelvin, Pa is local atmospheric pressure in kilopascal, and Pstd is standard barometric pressure (101.325 kPa).

PMU is a low-cost monitoring method compared to other methods that use chemiluminescence technologies and ultrasonic photoacoustic sensors, in addition to being accurate and easy to install. However, some precautions must be observed, such as the calibration of the sensors and the possibility of condensation of ammonia in the sampling tubes, thus contributing to the saturation of the equipment [22,30,55,56].

Despite all the progress in research and efforts to develop and expand evaluation characteristics of ammonia measurements over the years, this topic remains somewhat challenging for the reality of animal production facilities in tropical climate areas, which holds attributed part of the animal foods produced in the world. Ammonia concentrations in the agroindustry continue to increase, but concerns about the impacts of ammonia emissions on the air quality of facilities, the global climate, and its deposition in the soil are also growing [57]. Thus, it is imperative to develop policies to control and mitigate gas emissions to preserve and ensure the sustainability of animal production, the health of animals and people, and the reduction of environmental impacts [9].

1.5. Ammonia Emission Inventories

An ammonia emission inventory is an estimate of how much ammonia has been emitted into the atmosphere over the course of a year by one or more agricultural practices in each region. Its conduction can contribute to the development of public mitigation policies since its data help in the prognosis of the effectiveness of the implementation or even of the cost of the measure to be implemented [58]. An emission inventory is conducted following a methodology which consists of determining the population of animals in the region in which the inventory is to be carried out and how much ammonia has been released into atmosphere using an emission factor taken from the literature or calculated by researcher [58,59].

Several ammonia emissions inventories have already been developed for various sectors of the agribusiness in several countries. For animal production, ammonia emission inventories from beef and dairy cattle [23,24,60], swine [25], and poultry farming [3,24,26] already exist. Table 1 shows the results of ammonia emission inventories originating, specifically from poultry, carried out by different authors, in different countries.

Table 1. Annual emission of ammonia (kT NH_3 year^{-1}) by poultry in several countries.

Reference, Local	Emission Factor (g NH_3 Bird^{-1} Day^{-1})	Ammonia Emission (kT NH_3 Year^{-1})
Misselbrook et al. (2000) [23], UK	0.52	43 [1]
Hutchings et al. (2001) [24], Denmark	0.55	5.3 [2]
Mendes et al. (2014) [45], Brazil	0.27 ± 0.07 [3]	-
Gates et al. (2008) [26], USA	-	323.65 [4]
Osorio et al. (2017) [3], Colombia	0.30 ± 0.23 [5]	8.41 [5]

[1] It includes emissions from housing, storage, land spreading, and outdoors. [2] It includes emissions from housing, storage, and land spreading. [3] Emission factor determined in natural ventilation facilities. [4] Estimated values considering reused litter, the emission factor varies according to the model proposed by Gates et al. (2008) [26]. [5] Estimated values for natural ventilation facilities.

Misselbrook et al. (2000) [23] conducted an inventory of annual ammonia emissions in the United Kingdom. The calculated emission considered the estimated contribution of each class of animals (swine, cattle, poultry, and sheep) and the contribution of agricultural practices. Statistical data from agricultural censuses and emission factors described by Goot Koerkamp et al. (1998) [11], Demmers et al. (2001) [61], Jarvis et al. (1991) [62], and Peirson et al. (1995) [63] were used.

Hutchings et al. (2001) [24] developed an ammonia emission inventory for Denmark. The model used considered the contribution of each class of livestock and of agricultural practices such as fertilizer use, harvesting, and land spreading. Emission factors described by Jarvis et al. (1989) [64,65] and Pain (1989) [66] were used.

Mendes et al. (2014) [45] calculated the ammonia emission factor in broiler facilities with natural and mechanical ventilation systems. The ventilation rate was calculated according to the method described by Pedersen et al. (2008) [67], and the ammonia emission rate according to Equation (6), described by Barreto-Mendes et al. (2014) [8].

$$NH_3ER = Q \times \Delta[NH_3] \times W_{NH3} \times {V_{NH3}}^{-1} \quad (6)$$

where NH_3ER is ammonia emission rate in grams per bird per day, Q is the ventilation rate in cubic meters per bird per day, $\Delta[NH_3]$ is the difference between the concentration of ammonia inside and outside the facility in ppm, W_{NH3} is molar mass of NH_3 (17.031 g mol^{-1}), and V_{NH3} is molar volume of NH_3 under standard conditions (0.0245 m^3 mol^{-1}).

Sheppard et al. (2011) [60] quantified the concentrations and the emission rate of NH_3 in a commercial composting facility for laying poultry manure and evaluated the diurnal and seasonal oscillations. Continuous monitoring was carried out over a month in each season of the year, over two years. The daytime variations were significantly greater than the nighttime variations, mainly due to thermal conditions and composting management operations. An annual emission of 0.218 kT NH_3 in bird manure composting facilities was estimated. The emission rate was calculated according to Equation (7).

$$ER = Q_{total} \times (C_{NH3o} - C_{NH3i}) \times 24 \times N^{-1} \quad (7)$$

where ER is ammonia emission rate of the composting unit in grams per bird per day, Q_{total} is total ventilation rate using standard dry air conditions in cubic meters per hour, C_{NH3O} is ammonia concentration at the exhaust fan outlet of the facility in milligrams per cubic meter, C_{NH3I} is ammonia concentration inside the facility in milligrams per cubic meter, and N is total number of birds inside the facility.

Gates et al. (2008) [26] developed a methodology to carry out an inventory of ammonia emissions in poultry facilities for the state of Kentucky, in the United States. In this work, a statistical survey was carried out using data from the USDA NASS (United States Department of Agriculture National Agricultural Statistics Service) and USDA ERS (United States Department of Agriculture Economic Research Service) about broiler production. Equation (8) shows a linear model that considers the condition of the litter and the age of the birds to estimate ammonia emissions.

$$ER = 0.031 \times a \quad (8)$$

where ER is ammonia emission rate in grams per bird per day, and a is age of birds in days for cases of reused litter. For new litter, this value varies according to the age of the birds, and up to seven days, a is equal to zero, and above seven days, a is calculated according to Equation (9).

$$a = \text{Age of birds} - 6 \quad (9)$$

The parameters specified by the inventory were the population of chickens by productive cycle, the commercial weight, the age of the animals, the condition of the litter, and the period between productive cycles, where the cleaning and maintenance of the facilities occurs, adopted as seven days. This method can be adapted for emissions of other gases in broiler facilities if the due factors of age and litter condition are observed. An annual emission in the state of Kentucky was estimated at 8.8 kT NH_3 and 11.7 kT NH_3 considering new and used litter, respectively, and for the USA, an annual emission of 240 and 324 kT NH_3 was estimated considering new and used litter, respectively.

Osorio et al. (2017) [3] developed an annual ammonia emission inventory for the Department of Antioquia in Colombia. Thirty broiler facilities were selected, of which fifteen facilities had a mechanized ventilation system and fifteen facilities had a natural ventilation system. To obtain the daily ammonia emission factor in facilities with natural ventilation, the method proposed by Osorio et al. (2014) [50] was considered. Data from the agricultural census conducted by FAO (Food and Agriculture Organization) were used. The data such as number of facilities with natural and mechanized ventilation and population of broiler birds were multiplied by the emission factors obtained, reaching a total emission for Department of Antioquia. An annual emission of 8.41 kT NH_3 $year^{-1}$ in facilities with natural ventilation and 0.14 kT NH_3 $year^{-1}$ in facilities with mechanized ventilation was estimated. To obtain the daily ammonia emission factor in facilities with mechanized ventilation, Equation (10), proposed by Wheeler et al. (2006) [36], was used.

$$ER = Q \times M \times (NH_3e - NH_3i) \times 10^{-6} \times \frac{MV_{NH3}}{MV} \times \frac{Tstd}{Ta} \times \frac{Pa}{Pstd} \quad (10)$$

where ER is NH_3 emission rate of the facility in grams per bird, Q is air flow inside the facility measured at five centimeters from each upper foam, under natural conditions of temperature and pressure in cubic meters per hour per kilograms, M is average mass of birds in the facility in kilograms per bird, NH_{3e} is average NH_3 concentration outside the facility in ppm, NH_{3i} is average NH_3 concentration inside the facility in ppm, Wm is molar mass of NH_3 (17.031 g mol^{-1}), Vm is molar volume of NH_3 at standard temperature and pressure (24.14 L mol^{-1}), Tstd is standard temperature (273.12 K), Ta is absolute ambient air temperature in kelvin, Pa is local atmospheric pressure in kilopascal, and Pstd is standard barometric pressure (101.325 kPa).

A problem that involves drawing up an inventory of ammonia emissions is the uncertainty associated with measurements. Making accurate measurements of ammonia concentrations and ventilation rates inside a facility with a natural ventilation system proves to be a challenge [67]. In facilities with natural ventilation systems, the air inlets and outlets are not well defined, oscillating according to the external conditions. Thus, techniques that measure air flow indirectly can lead to an erroneous ventilation rate, mainly due to the imperfect mixture of air inside the facility [68,69].

In relation to models that predict the emission of ammonia, for validation of the referred model, data from experimental collections are necessary. The lack of reference data on ammonia emissions is an important gap; if not filled, little can be done about the validation of a model [70]. The quality of the data collected and the emission factors adopted are directly related to the quality of the ammonia emissions inventory. If real ammonia emissions data are missing in each region where an inventory was carried out, it will be difficult to quantify the uncertainty associated with the calculated emission factors [71].

2. Conclusions

Strategies such as the use of additives and the use of diets with lower levels of crude protein are some examples of measures that can contribute to reduce ammonia emissions in broiler production facilities. The SMDAE and PMU methods can be adapted to measure the ammonia emission in poultry facilities with the constructive typology of countries with hot climates, such as Brazil. In several countries around the world, there are already initiatives that make it possible to conduct inventories of ammonia emissions from poultry farming. The quantification of uncertainties about ammonia emission inventories and emission factors is a challenge to be overcome. In view of the lack of real ammonia emission data, further studies are required to fill these gaps.

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