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# EVALUATION OF DIFFERENT METHODS FOR DETERMINING AMMONIA EMISSIONS IN POULTRY BUILDINGS AND THEIR APPLICABILITY TO OPEN FACILITIES

## EVALUACIÓN DE DIFERENTES METODOS PARA DETERMINAR EMISIONES DE AMONIACO EN GALPONES AVICOLAS Y SU APLICACIÓN EN INSTALACIONES ABIERTAS

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**ABSTRACT:** In regions of tropical and subtropical climates, nearly all installations used for intensive broiler chicken production and other animals of economic interest operate as curtain-sided open structures with assisted mechanical ventilation. The lack of ventilation control in these facilities, along with wind direction and velocity effects on ventilation uniformity, complicates calculation of the quantity of gases (ammonia and others) generated by the litter at a given moment. This fact constitutes a pitfall when evaluating the polluting potential of open environments, and when comparisons with data encountered in closed environment facilities used in temperate climates need to be done. All developed countries of Europe and North America already possess methodologies to determine gas emissions in closed installations commonly found in these regions. Therefore, the objective of the present study was to evaluate some specific methodologies used for determining ammonia emissions from broiler houses located in countries of Europe and the United States, and verify the possibility for application of these methodologies to open structures commonly found in Brazil and other countries of South America. A quantitative evaluation showed that the methods with best characteristics for adaptability to the operational conditions and the different types of conditioned environments of buildings with positive pressure or natural ventilation systems were the internal tracer gas, the portable monitoring unit (PMU) and the mobile air emissions monitoring unit (MAEMU). According to the results, model-based approaches that use mass balance and passive diffusion samplers such as the "Ferm Tube" and the Saraz Method for Determination of Ammonia Emissions (SMDAE) proposed by Osorio (2010), can also be adapted to different operational conditions for open buildings.

**KEYWORDS:** Ammonia emissions, air pollution, animal production, air quality, ventilation.

**RESUMEN:** En regiones de clima tropical, como es el caso de Brasil, básicamente todas las instalaciones usadas en la producción intensiva de pollos de engorde y de otros animales de interés económico que trabajan gran parte del tiempo con instalaciones abiertas y con ventilación forzada. La falta de control sobre la masa de aire renovada en cada intervalo de tiempo, bien como de la velocidad y uniformidad del aire de la ventilación que dificulta el cálculo de la cantidad de gases (amoníaco y otros) generados por la actividad en determinado momento. Este hecho constituye una dificultad en la evaluación del potencial contaminante ocurrido en estos ambientes abiertos, bien como en la comparación con los datos encontrados en los galpones cerrados utilizados en climas templados, ya que todos los países desarrollados de Europa y América del Norte disponen de metodologías para determinar el valor de las emisiones de gases en las instalaciones cerradas utilizadas en este tipo de regiones. Por lo tanto, este trabajo, busca analizar algunas metodologías usadas para determinarlas tasas de emisión de amoníaco en galpones de pollos de engorde cerrados, en países de Europa y de Estados Unidos de América (USA), y verificar la posibilidad de aplicarlas, a través de su adaptación y empleo en estructuras abiertas usadas en el Brasil y en otros países de América del

Sur. Una evaluación cuantitativa, muestra que los métodos con mayores características de adaptación a las condiciones de operación y a los diferentes tipos de acondicionamiento ambiental de galpones con sistemas de ventilación de presión positiva o con ventilación natural, son el método de trazado de sistemas de gases interno y de unidades de monitoreo continuo con las unidades portátiles de monitoreo (PMU) y unidades de monitoreo móviles para emisiones al aire (MAEMU). Métodos tales como el método que usa balance de masa y aquellos de difusión pasiva como el "Ferm Tube" y el método Saraz, para la determinación de emisiones de amoníaco (Saraz method for determination of ammonia emissions – SMDAE) propuesto por Osorio (2010), indican también que pueden ser adaptados para las diferentes condiciones de operación de los galpones abiertos.

**PALABRAS CLAVE:** Emisiones de amoníaco, contaminación aérea, producción animal, calidad del aire, ventilación.

## 1. INTRODUCTION

The understanding and control of ammonia ( $\text{NH}_3$ ) emissions to the atmosphere is very important, due to ecological effects of emissions when deposited in soils and by its direct relation with  $\text{NH}_3$  concentrations. High levels of  $\text{NH}_3$  in the air also have a negative effect on health and productivity of animals and people [1-2]. In general,  $\text{NH}_3$  emissions generated from enclosed livestock confinements have been evaluated as the  $\text{NH}_3$  concentrations measured at the exhaust fans multiplied by air exchange rate through the installation. However, despite this being a simple concept, both measured concentrations and ventilation rates are difficult to precisely quantify in poultry buildings due to their size and the non-homogeneous nature of factors such as litter moisture content, pH, temperature, etc., that affect those variables both in space and time [3-4-5].

Therefore, in the case of open installations, such as those often encountered in Brazil, the quantification of  $\text{NH}_3$  emission becomes more complex. One of the aspects of greatest importance in regards to  $\text{NH}_3$  emissions is calculation of the ventilation rate in the specific type of installation. Determination of this variable in naturally ventilated buildings, as well as in curtain-sided housing with mechanical ventilation, can be complicated due to its instability and variability, the latter due to strong opposing natural air currents contrary to flow of the fans, generating different flow rates at each moment [6].

Although there are instruments that directly measure air speed in various directions like 3-D Doppler/Ultrasonic sensing technologies, they are expensive and only measure at a point, not over an area. Because broiler buildings are very long it would be very expensive to apply that technology. More affordable techniques have been developed such as that used by [7] which consists on a particle image velocimetry (PIV) system to simulate real conditions of air behavior. There is also

the tracer gas method [8-9] which helps in precisely understanding the air velocity distribution inside installations; however calculation of the ventilation rate is still extremely complex.

General methods used to determine  $\text{NH}_3$  emissions available to date for closed installations present reasonable accuracy as reported by [2,3,5,10-13-]. Nevertheless, application of these methods is very difficult in conventional poultry buildings, principally due to the need to adapt to the various operating conditions within the installations.

## 2. MATERIAL AND METHODS

In this study a methodology was applied for the qualitative and quantitative evaluation of the main methods available for determining  $\text{NH}_3$  emissions from poultry houses, which were chosen based on primary and secondary information. The evaluation of each of the studied methods was performed based on their positive and negative characteristics, each on a scale of 0 to 10. Zero signifies no condition for use, 1-3 poor, 4-6 regular, 7-9 good, and 10 excellent. For the evaluation of the chosen methods, a panel of 15 researchers, considered international experts in the area, were interviewed. The panel consisted of scientists from Brazil, Colombia, the United States and the Netherlands and the selection criteria was the area of expertise in gaseous emissions from livestock, years of experience and number of published peer-reviewed papers in the field. The results obtained from the interviews were used to grade each of the methods, allowing them to be ranked.

The evaluated characteristics of each methodology were: (1) Cost of method if applicable for buildings with mechanical ventilation with positive pressure; (2) Cost of method if applicable for buildings with mechanical ventilation with negative pressure; (3) Cost of method if applicable for buildings with

natural ventilation; (4) Precision of the method for buildings with mechanical ventilation under negative pressure; (5) Precision of the method for buildings with mechanical ventilation under positive pressure; (6) Precision of the method for buildings with natural ventilation; (7) Degree of difficulty for data acquisition; (8) Operational efficiency in systems with natural ventilation; (9) Operational efficiency in mechanically ventilated systems under negative pressure; (10) Operational efficiency in mechanically ventilated systems under positive pressure.

The statistical analysis was performed with the software SAS 9.2® on the grades given by each panelist and consisted of an analysis of variance (ANOVA) in a factorial 7 X 10 (methods X characteristics), with the factor “panelist” being considered a random variable. The data sets were tested against the null hypothesis ( $H_0$ ) that there is no significant difference between grades attributed to different methods. The analysis was performed with PROC GLM, and the mean grades were compared to one another and ranked with the Tukey’s Studentized Test.

### 3. DETERMINATION OF NH<sub>3</sub> EMISSIONS AND AIR VELOCITY DISTRIBUTIONS

Seven of the most utilized methods available to determine NH<sub>3</sub> emissions in closed poultry buildings, were selected as the most applicable for Brazilian conditions and were evaluated, the advantages and disadvantages of each were highlighted. The chosen methods were: External and internal tracer gas balance, the passive diffusion proposed by [14]. “Ferm Tube” passive flow, the portable monitoring unit (PMU), the mobile air emissions monitoring unit (MAEMU) Method, Derock Method [15] and Model-based approach that uses mass balance.

#### 3.1. Tracer gas ratio technique - TGRT

The TGRT consists of establishing a similitude between the emission rate and concentration of a gas with chemical and physical characteristics similar to the gas of interest, denominated the “tracer gas”, with that of the species under investigation, i.e. the “target gas”. It is very important that the emission rates or concentrations of both tracer and target gases are measured both at the same point in space and same

instant [16]. Carbon monoxide (CO) has been used as a tracer by [17,8,16], which provides the advantage of being strongly absorbed by infrared sensors and its concentration is easily monitored since it has roughly the same density of air. However, sulfur hexafluoride (SF<sub>6</sub>) is a most widely used tracer and its concentration can be measured by gas chromatography [10]. In addition, CO<sub>2</sub> is also used with good results, as reported by some studies such as [18].

The tracer gas ratio technique can be performed externally (under the influence of dominating winds) or inside the building (not depending on a particular wind direction). In both cases it is necessary to precisely know the location of all NH<sub>3</sub> emitting sources and distribution of the concentrations.

As for calibration procedures of the TGRT, the analyzers for both target and tracer gases are usually tested against calibration gases of known concentrations, and calibrated if the discrepancy exceeds the tolerance limit, which is usually 5%.

For typical poultry buildings in tropical climates, where the structures are generally located in the east-west direction, and both the predominant winds and lateral openings of the buildings are in the north-south direction, the TGRT, either used externally or internally, can be used depending on the operational conditions since the air flow that enters and exits the building does not always present uniform conditions along its length. For buildings with positive or negative pressure ventilation, and either open or closed structure, the external tracer gas ratio technique is recommended, seeking to perform measurements near the perimeter of the structure and facing the predominant winds.

In the case of open structures with natural ventilation, with no continuous predominant winds or uniform velocities, the internal tracer gas ratio technique was shown to be the best suitable for determining NH<sub>3</sub> emissions [17,8]. Data acquisition should be done near the perimeter of the structure for the external injection of tracer gas [19-20]. The internal method is less susceptible to changes in wind direction than the external.

To measure NH<sub>3</sub> concentrations in the case of the external TGRT, the process most commonly recommended is the

AMANDA (Ammonia Measurement by Annular Denuder sampling with on-line Analysis) system. This method has an excellent efficiency in terms of precision, being capable of detecting  $\text{NH}_3$  at very low concentrations (0.001 ppb). However in terms of cost, the AMANDA system may be the most costly [16,21,22].

### 3.2. PMUs and MAEMUs METHODS

This method consists in determining  $\text{NH}_3$  emissions with instruments for continuous monitoring of low and medium concentrations. These devices are portable and easily encountered on the market, such as the photoacoustic analyzer (Innova Tech Instrument), and have been utilized in studies conducted by [6,23-27].

Based on the need for continuous monitoring of  $\text{NH}_3$  in broiler houses and the difficulty of acquiring precise instruments due to their elevated costs, [3,6], developed a device denoted as the portable monitoring unit (PMU). This device has a lower costs compared to high precision thermal oxidation monitors (chemifluorescence) and photoacoustic analyzers which were used in the studies performed by [4].

References [28-29], performed studies aiming to evaluate the efficiency of the PMUs for continuous monitoring in commercial poultry buildings in the United States equipped with negative pressure tunnel ventilation systems. The authors made comparisons between the concentration and emission of  $\text{NH}_3$  obtained by a mobile air emissions monitoring unit (MAEMU) [29], which is a reliable reference unit and consists of a trailer where the instruments necessary for  $\text{NH}_3$  gas emission monitoring are located. [28], reported that  $\text{NH}_3$  concentration and emission data obtained by the PMUs and the MAEMUs present significant statistical differences, and one reason for that was the sequencing of sampled ventilation rate and measured concentration. However, if these variables are lined up there is still a difference, but that can be adjusted.

All these methods must also have other instruments along with the  $\text{NH}_3$  concentration detectors, that continuously measure temperature, air relative humidity and atmospheric pressure, to determine correction factors. The determination of the building ventilation rate, can be done according to the type of ventilation system (mechanically or natural ventilation)

and the kind of technology available (e.g., calibration of exhaust fans if mechanically ventilated or use of tracer gases if naturally ventilated). This is initially a disadvantage due to the initial investment costs, but the major advantage is its relatively good accuracy as compared to other methods.

The calibration of these methods is done similarly to what was described for the TGRT method, e.g. use of calibration gases for the gas analyzers.

Both of these methods have been employed mainly in closed structures which operate under negative pressure with mechanical ventilation; however they can also be adapted to open structures. It is understood that these methods can also be applied in the case of structures with natural ventilation; nevertheless, for open structures there should be a greater number of monitoring points inside the structure at different heights from the litter (at least two) and near the air outlets, combined with a constant monitoring of wind speed and direction along the perimeter of the structure. However this adaption makes this method complex and sometimes unfeasible due to the number instruments required.

In addition, the applicability of PMU's or MAEMU's to Brazilian conditions should be investigated due to the existence of low levels of  $\text{NH}_3$  observed in Brazilian poultry barns. It has been shown that poultry barns in tropical conditions seem to be "over ventilated" as compared to those located in temperate regions [30]. Which could cause litter moisture content to be lower resulting in lower release of  $\text{NH}_3$ , which can be difficult to detect and require sensors/analyzers with lower detection limit, and thus more expensive.

### 3.3. Derock Method

This method has been utilized by [31], and was later improved by [15] in closed hog confinements with negative pressure ventilation, in which gases are removed via a chimney. In this system, the buildings are provided with equipment for measurements of concentration and ventilation rate at any given instant, intermittently. Compared to methods which continuously measure  $\text{NH}_3$  emissions, this is a lower-cost option. The method has a linear model which correlates  $\text{NH}_3$  concentration with other variables, such as external temperature, ventilation rate and animal live body weight.

The validation of the model was done by comparing the results with those obtained by continuous  $\text{NH}_3$  analyzing devices, only four times a day at any time. Maximum errors were limited to 10%, when compared to measurements taken during the whole day.

It is therefore understood that this method can also be used in open installations equipped with positive or negative tunnel ventilation in tropical climates when the ventilation system is operating with the lateral curtains closed. However, it is necessary to adapt a statistical understanding of emission behavior to its conditions during the entire year in order to reduce the number of experiments necessary. It initially appears that this method is not easily applied to natural ventilation systems with large lateral openings.

### 3.4. Passive flux methods

#### 3.4.1. Ferm Tube (Passive flux samplers)

According to [10], the first passive flux sampler was developed by Ferm (1986) and reported by [32], denominated the “Ferm Tube”. This method has been reported by [20] and [21], and has mainly been applied to determine  $\text{NH}_3$  emissions in cattle confinements.

In the case of poultry houses, which work either with closed conditions (mechanically ventilated under positive or negative pressure), or open conditions (naturally ventilated) this method can be used with good accuracy since they have direct air fluxes exiting the structure. However, when this type of structure operates with only natural ventilation, the samplers should be maintained in the environment under study for as long as possible since many times there is not a single wind direction and the wind speeds can be low, which may cause errors in the obtained emission values.

Costs may be high when using this method, depending on the number of samples required, and also because sampling time is in hours which does not allow easy correlation with other independent variables to obtain statistical models.

#### 3.4.2. SMDAE method proposed by Osorio (2010)

The Saraz Method for Determination of Ammonia emissions (SMDAE) proposed by [14], consists of a

passive diffusion collector, based on a polyurethane sponge whose function is to absorb the gaseous  $\text{NH}_3$  emitted by the building. Each sponge is impregnated with a solution of sulfuric acid and glycerin, causing fixation of  $\text{NH}_3$  by microdiffusion. Acidic solution  $\text{NH}_3$  concentration is then quantified by acid – base titration, using the Kjeldhal method.

Open installations with closed curtains under either positive or negative pressure that usually present a predominant air flux direction are ideal for the implementation of the SMDAE method. When dealing with structures with lateral openings and only natural ventilation to quantify  $\text{NH}_3$  emissions, it is necessary to place the prototype at both sides, for a time period greater than two hours [14]. This results in a greater number of samples and thus higher cost. Nevertheless, because this methodology scans a greater area for gas capture, as compared to methods in which gaseous concentrations are sampled in a very small number of locations (usually only at inlets and outlets), and also because of the simplicity of the collector, it is less onerous than the others.

One of the limitations is that this method operates best for broiler chickens older than 14 days, when the quantity of manure can cause greater  $\text{NH}_3$  production if the litter is in its first cycle of use, but it will work just fine for litter from the second cycle of use on. This is because one of the disadvantages of the system is that it can only accurately evaluate  $\text{NH}_3$  conditions when concentrations are greater than 1 ppm, and this concentration is rarely reached during the first two weeks, if new litter is being used. Therefore, according to [14], this method can be further improved in order to be viable at  $\text{NH}_3$  concentrations less than 1 ppm, and to account for factors such as environmental conditions, stocking density and type of litter.

Another limitation of the method is the fact that concentrations of  $\text{NH}_3$  are determined by laboratory analysis, which can be either expensive or impossible to do in some places in Brazil.

### 3.5. Model-based approach that uses mass balance

The mass balance method takes into consideration all forms of nitrogen inside a structure, generated by animal urine and manure which are deposited onto the beds. To

apply this method a mass balance is performed in which a clear understanding is necessary of the relationship of the feed characteristics, quantity of urine and feces produced by the animal, as well as the  $\text{NH}_3$ -N fraction present in the total  $\text{NH}_3$  nitrogen (TAN) of the manure.

To determine  $\text{NH}_3$  emissions using this method, [33-34], mathematical models must be generated based on general mass transfer equations, and thus developing empirical equations to determine the convective coefficient of mass transfer for different flows and geometric surfaces. For animal production in tropical countries, where different types of poultry bedding are used and reutilized and where combinations of management systems using natural and mechanical ventilation with open and closed systems are common, it is very difficult to employ a single mathematical model for the complete variety of operational conditions. Therefore it is necessary to generate mathematical models for each condition, where the greatest difficulty is encountering the convective coefficient of mass transfer, an important parameter for emissions determination.

The implementation cost of this methodology is not very high in comparison with the previously described methods. Similarly, the procedures to obtain the parameters required for the model are not difficult to be performed. However, the method requires qualified personnel for data collection during the experimental period.

#### 4. QUANTITATIVE ANALYSIS OF THE METHODS

The results of the ANOVA suggested that the representativeness of the relationship between method and grades with the tested statistical model is overwhelming ( $P$ -value > 0.0001). Results indicate that attributed grades are significantly affected by the type of method.

Fig. 1 presents a quantitative qualification of the possibilities for use of the  $\text{NH}_3$  determination methods practiced in closed buildings, with respect to their applicability in open or partially open structures typical of animal production in tropical or subtropical climates, as in the case of Brazil and other South American countries.

Mean grades by method and characteristic were plotted on the chart shown in fig. 1. One can see that higher mean grades were attributed to methods 2 and 3 (internal tracer gas and use of PMU's or MAEMU's, respectively). Confidence intervals at the level of 95% ( $\text{CI}_{95\%}$ ) of the grades for methods 2 and 3 are [6.9; 7.1] and [6.7; 6.9], respectively. It can be verified from fig. 1 that the internal tracer gas method was classified as having the greatest potential in the overall evaluation. It was also verified that the internal tracer gas method was better than the external tracer method for both open and closed structures with natural ventilation and positive or negative pressure. The greatest disadvantage of this method is its high cost, while its greatest advantage is accuracy.

The method for determining  $\text{NH}_3$  concentration and air speed distributions, such as those used by [5,24], and that developed by [6] like the PMUs and MAEMUs, can also be used with good accuracy. However it can be observed that the greatest disadvantages for the MAEMUs as opposed to the PMUs, is the high initial cost since various monitoring points along the perimeter of the structure are necessary, especially in the case of natural ventilation. After compensating for the initial costs, with the system already in operation, the effect of costs evaluated in fig 1 can be improved, making it possible to apply this method in tropical climates for open installations with different operational managements.

The analysis also indicated that methods 4 and 7 ("Derock" and nitrogen mass balance respectively) were considered by the panelists as the worst methods to be used for measurement of  $\text{NH}_3$  emissions in poultry barns. It can be seen from fig. 1 that the Derock method was considered applicable to mechanically ventilated buildings, but would not be as appropriate for naturally ventilated buildings, as evidenced by a lower grade ( $\text{CI}_{95\%} = [6.2; 6.4]$ ).

Despite its good accuracy, the Derock method presented disadvantages such as the difficulty for its use in open installations, as well as difficulties for statistical adaption to each region and conditions. These facts reduce its suitability.

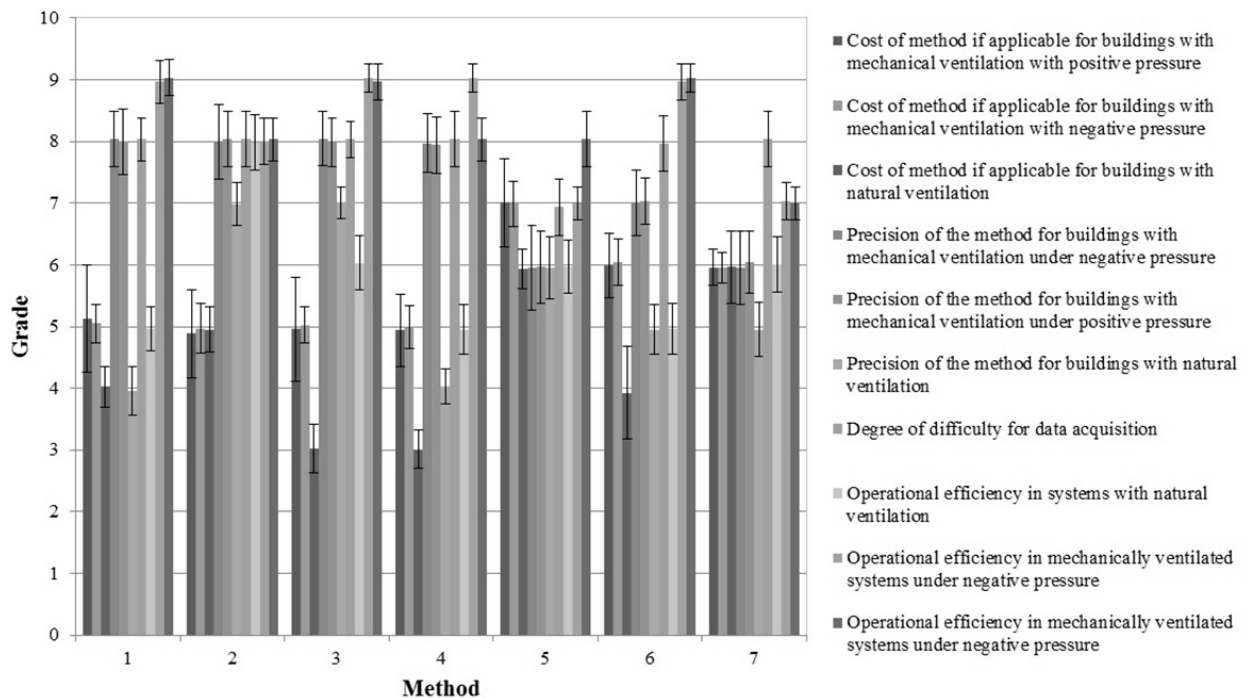
The nitrogen mass balance method received relatively lower grades in nearly all characteristics, with a 95%

CI of [6.2; 6.4]. This method is good to predict NH<sub>3</sub> emissions generated in an animal confinement, for both conditions of natural ventilation and positive or negative mechanical ventilation. The principal disadvantage of this method is the difficulty to find the mass transfer coefficient, especially under conditions of natural ventilation, where predominant winds vary in terms of velocity and direction.

Methods 1, 5 and 6 (external tracer gas, SMDAE and Ferm tubes, respectively) were considered statistically the same by the panelists, with CI<sub>95%</sub>'s of [6.4; 6.6], [6.5; 6.6] and [6.5; 6.7], respectively. These methods showed slightly poorer qualifications as compared to continuous monitoring and internal tracer gases. One possible reason for that is the fact that they have greater accuracies when NH<sub>3</sub> concentrations are high (>0.5 ppm). However, their applicability in poultry buildings with positive and negative ventilation, and natural ventilation can be applied with greater reliability, given the operational conditions of these buildings. In the case of natural ventilation, the passive diffusion method with "Ferm Tube" and SMDAE can

be as accurate as internal tracer gases once the birds are more than 14 days old according to [14]. However, more sampling points are required due to fluctuation of wind direction which increases costs due to the higher number of laboratory analyses. To account for changes in wind direction, samplers should be installed near all the possible outlets of the barn, and additional monitoring of wind speed and direction should be done to allow detection of shifting in outlet location with change in wind conditions. The main disadvantage of the passive flux methods analyzed here is the fact that they do not allow continuous monitoring of emissions and the long exposure time depending on wind speed and direction conditions.

The external tracer gas method functions well with negative and positive pressure systems with predominant winds; however, when dealing with natural ventilation with winds in various directions and different speeds, this method may not present good reliability. The costs of this method can also be quite high, making qualification of this method poor compared to the others.



**Figure 1.** Average mean grades and standard deviations

Methods are labeled as follow: (1) external tracer gas; (2) internal tracer gas; (3) PMU and MAEMU; (4) Derock; (5) SMDAE protocol; (6) "Ferm" tube for passive flux and (7) nitrogen mass balance.

## CONCLUSIONS

From the presented quantification and discussions, the reliability of a given technique for determination of NH<sub>3</sub> emissions in open or partially open animal structures can be defined as being subjective; however, each given technique may be considered as to whether it is applicable or not, depending on the characteristics of the building, its management (type of litter, stocking density, fan conditions, etc.), economic resources available and accuracy needed, and the best technique for each case may be chosen by the researcher based on the analysis of all the aforementioned characteristics.

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