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## Methods for determining the emission of greenhouse gases in swine farming<sup>1</sup>

### Metodologias para determinação da emissão de gases de efeito estufa na suinocultura

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#### HIGHLIGHTS:

*The emission of greenhouse gases in swine farms contributes to global warming.*

*The method used for quantification of greenhouse gas emissions from swine farming must be accurate and adapted to Brazil.*

*The simplified method is reliable and can replace the conventional continuous method.*

**ABSTRACT:** Swine production systems contribute to emission of greenhouse gases (CO<sub>2</sub>, N<sub>2</sub>O, and CH<sub>4</sub>) and ammonia (NH<sub>3</sub>) into the atmosphere. Therefore, the objective of this study was to evaluate methods for determining the emissions of ammonia and greenhouse gases (GHG) in a commercial swine production unit with natural ventilation during the finishing phase. The concentrations of gases in the air were measured using a gas analyzer (INNOVA 1412), and the flow emission was calculated by considering the ventilation rate and the differences in gas concentration between the interior and exterior of the installation. The results showed that the emission flow obtained via the simplified method in [g per swine h<sup>-1</sup>] was 2.689, 0.30, 4.39, 13.55, and 3.273 for CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub>, NH<sub>3</sub>, and water vapor, respectively. The flow obtained using the continuous method in [g per swine h<sup>-1</sup>] was 574, 0.67, 19.50, 5.84, and 7.2 for CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub>, NH<sub>3</sub>, and water vapor, respectively. The proposed simplified method was highly accurate for estimating GHG emissions from swine production systems with natural ventilation.

**Key words:** swine farm, methane, ammonia, environment, global warming

**RESUMO:** Os sistemas de produção de suínos contribuem com emissões de gases de efeito estufa (dióxido de carbono - CO<sub>2</sub>, óxido nítrico - N<sub>2</sub>O e metano - CH<sub>4</sub>) e amônia - NH<sub>3</sub> para a atmosfera. Portanto, o objetivo deste estudo foi avaliar metodologias para determinação das emissões de amônia e gases de efeito estufa em uma unidade de produção comercial de suínos durante a fase de terminação, que possui ventilação natural. Foram medidas as concentrações de gases no ar pelo analisador de gases (INNOVA 1412) e foi calculada a vazão de emissões considerando a taxa de ventilação e as diferenças de concentração de gases entre o interior e o exterior da instalação. Os resultados mostraram que a vazão de emissão obtida pela metodologia simplificada em [g suíno por hora] foi: 2,689 para CO<sub>2</sub>, 0,30 para N<sub>2</sub>O, 4,39 para CH<sub>4</sub>, 13,55 para NH<sub>3</sub> e 3,273 para vapor d'água. A vazão obtida para a metodologia contínua em [g suíno por hora] foi de 574 para CO<sub>2</sub>, 0,67 para N<sub>2</sub>O, 19,50 para CH<sub>4</sub>, 5,84 para NH<sub>3</sub> e 7,2 para vapor d'água. A metodologia simplificada foi altamente precisa para estimar as emissões de GEE em sistemas de produção de suínos com ventilação natural.

**Palavras-chave:** granja de suínos, metano, amônia, meio ambiente, aquecimento global

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## INTRODUCTION

The world population is estimated to reach nine billion by 2050. Therefore, the demand for subsistence resources, mainly for food of animal origin, will increase. The consumption of pork meat is an alternative, causing an increase in the production of number of animals, which in turn increases the amount of waste produced, in addition to the emission of greenhouse gases (GHGs) into the environment.

Increasing concentrations of greenhouse gases in the atmosphere are a cause of global warming. The gases primarily responsible for this effect are carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O). Greenhouse gas emissions from livestock activities account for approximately 18% of the total emissions. Of this total, 13% resulted from swine farming (Philippe & Nicks, 2015). The ONU environment has pointed out numerous environmental losses related to unsustainable agricultural practices (Gelinski Neto et al., 2019).

Several estimates of GHG emissions from swine production systems have been made on the European and North American continents, where buildings and climate differ from Brazil (Samer et al., 2012). Global warming and the increase in atmospheric concentrations of GHGs have resulted in environmental concerns, which necessitates the evaluation of the contribution of swine farming activities to these emission rates (Dortzbach et al., 2021).

Current methods used to quantify gaseous emissions based on continuous measurements are expensive and difficult to apply on a large scale (Haeussermann et al., 2008). Therefore, it is necessary to simplify the current methods to multiply the acquired data to estimate the emissions of the main GHGs generated in a swine production system. Moreover, the error in the calculated emissions should be controlled to be less than 30%.

The objective of this study was to evaluate methodologies for determining the emissions of ammonia and GHGs in a commercial swine production unit during the finishing phase, which has natural ventilation.

## MATERIAL AND METHODS

Data were collected from a commercial swine finishing farm located in the municipality of Alto Bela Vista, SC, Brazil (27° 18' 34" S and 51° 59' 30" W, altitude of 548 m) with predominant southeast (SE) and northeast (NE) winds. The climate is subtropical humid mesothermal Cfa with hot summers (average annual air temperature of 18-19 °C and average annual precipitation of 1700–1900 mm) according to the Köppen classification. Air temperature, relative air humidity, and rain data were collected from the farm using an automatic station.

The experimental building is oriented east-west and is 24.0 m long, 8.5 m wide and 2.60 m high. Its roof is a fiber cement tile with a lining made of plastic canvas and it has a threshold of 0.90 m. In addition, the rest of the sides are open, totaling a side opening area of approximately 81.6 m<sup>2</sup>. A total of 144 commercial hybrid swine from selected lines for lean meat deposition (Landrace and Large White), females, and

castrated males were randomly housed in 12 pens during the finishing phase.

The continuous methodology is considered the standard and allows a better characterization of emissions throughout the seasons and presents more robust data in relation to the real emission of gases; thus, it serves as a model for comparison with new methodologies (Haeussermann et al., 2008).

The simplified method consists of air collection in the internal and external environments of the building to determine the concentration gradient of the gases, validated through the carbon and nitrogen mass balance. The simplified methodology developed by Robin et al. (2013) was used to evaluate the emissions of gases generated inside and outside the building. This simplified method calculates the amount of CO<sub>2</sub> (carbon dioxide), CH<sub>4</sub> (methane), N<sub>2</sub>O (nitrous oxide) and NH<sub>3</sub> (ammonia) generated in a swine production system. According to Robin et al. (2013), this method allows the calculation of annual emissions from a swine production system while ensuring that the errors lie in the 20-30% range.

Data were collected for three months in the production unit, and the concentration (ppm) of gases in the air was collected in bags, inside and outside the farm for 45 min, three times a week on alternate days during the finishing phase. For greater representativeness of the samples, the air collected inside the building was throughout its length in the corridor and over the bays. By contrast, the air collected outside was sampled along its entire length, considering its sides, and this air was collected 3 m from the building for 45 min.

Collection was performed using an ELITE® suction pump with a flow rate of  $3.3 \times 10^{-6} \text{ m}^3 \text{ s}^{-1}$  connected to a TEDLAR collection bag (SKC®) with a volume of 10 L. The contents of the collectors were analyzed using infrared photoacoustic analyzer equipment (INNOVA1412®) to measure the concentrations of CO<sub>2</sub>, CH<sub>4</sub>, NH<sub>3</sub>, and H<sub>2</sub>O vapor.

Two air sampling points were installed for continuous gas measurements: one 1.2 m above the floor in a central span and the other 15 m away from the building, positioned at a height of 1.2 m from the ground. These two points were connected to an analyzer (INNOVA 1412), which suctioned air using two thin Teflon tubes (4 mm in diameter).

The air temperature and relative air humidity values were stored using a TESTO model 174H data-logger, installed inside and outside the building, totaling four pieces of equipment, two inside, installed at a height of 1.60 m from the floor and the other two outside 2.50 m from the ground. This equipment recorded the air temperature and relative air humidity measurements every 30 min.

The air velocity data were collected longitudinally at five distinct points in the building, three in its interior, and two in the exterior. At each point, according to the recommendations of Robin et al. (2013), 10 air velocity readings were performed to obtain the average velocity at the time of the gas emission measurement, inside and outside the building.

To calculate the gas flows generated in the building, it was considered the airflow coming out of the installation, the characteristics of the volumetric mass of the air, and the difference in gas concentration between the interior and exterior of the building expressed in terms of the mass

concentration for both nitrogen (N) and carbon (C), as recommended by Robin et al. (2013). This is expressed in Eq. 1.

$$\varphi = \varphi_{\text{Air}} \cdot \rho_i \cdot (C_i^m - C_e^m) \quad (1)$$

where:

$\varphi$  - emission of gas ( $\text{mg h}^{-1}$  per animal) dry air, estimated from the airflow, concentration of gases, and volumetric mass of dry air;

$Q_{\text{air}}$  - airflow coming out from the building ( $\text{m}^3 \text{h}^{-1}$ ), calculated from total heat, latent, and wind speed production ( $\text{m}^3 \text{s}^{-1}$ );

$C_i^m$  - mass gas concentration inside the building ( $\text{g kg}^{-1}$  dry air);

$C_e^m$  - mass gas concentration outside the building ( $\text{g kg}^{-1}$  of dry air); and,

$\rho_i$  - conversion factor of the volume of airflow passing through the installation in  $\text{m}^3 \text{h}^{-1}$  to the mass flow in kilograms of dry air per hour. This allows the application of the laws of conservation of mass and energy.

The use of these methods of airflow estimation by heat production aims to validate the data from the anemometer. In open buildings, the airflow rate varies significantly. To calculate, Eq. 2 was used.

$$\rho = \left[ \frac{P_{\text{Vap}}}{47.1 \cdot (T_{\text{ref}} + T_i)} + \frac{P_{\text{atm}} - P_{\text{Vap}}}{29.27 \cdot (T_{\text{ref}} + T)} \right] \cdot \frac{1}{\text{Grav}} \quad (2)$$

where:

$\rho$  - volumetric mass of air inside the installation ( $\text{kg m}^{-3}$ );

Grav - acceleration of gravity ( $9.81 \text{ m s}^{-2}$ );

47.1 and 29.27 - perfect gas constants for water vapor and dry air, respectively;

$T_{\text{ref}}$  - temperature of the critical point of water (273.15 K) ( $^{\circ}\text{C}$ );

$T_i$  - internal building temperature ( $^{\circ}\text{C}$ );

$P_{\text{Vap}}$  - partial pressure of water vapor in the air, also known as the mixing ratio (mmHg); and,

$P_{\text{atm}}$  - atmospheric pressure (Pa).

The law of ideal gases was used considering the ambient air temperature at the time of gas collection for gas conversion. This is expressed in Eq. 3.

$$C_i^m = C_i^v \cdot \frac{M_m}{V_m} \cdot \frac{M_m}{M_{\text{mol}}} \quad (3)$$

where:

$C_i^m$  - equivalent concentrations of C and N in gases ( $\text{mg m}^{-3}$ ), measured at an instant (C- $\text{CH}_4$ , C- $\text{CO}_2$ , N- $\text{NH}_3$ , N- $\text{N}_2\text{O}$ );

$C_i^v$  - measured concentration of gas (ppm);

$M_m$  - equivalent molar mass of C and N in the gas being considered ( $\text{CO}_2 = 12$ ,  $\text{CH}_4 = 12$ ,  $\text{NH}_3 = 14$ ,  $\text{N}_2\text{O} = 28 \text{ g mol}^{-1}$ );

$M_{\text{mol}}$  - molar mass of gas ( $\text{CO}_2 = 44$ ,  $\text{CH}_4 = 16$ ,  $\text{NH}_3 = 17$ , and  $\text{N}_2\text{O} = 44 \text{ (g mol}^{-1})$ ); and,

$V_m$  - molar volume corresponding to the molecular mass of the gas under local temperature and pressure conditions ( $\text{L mol}^{-1}$ ).

Using the observed gas concentration data and the internal and external psychrometric characteristics of the air, the gas flow inside the studied building was determined to obtain this productive variable in grams of gas generated by the swine daily as a function of the weight gain of these animals.

Waste and feed samples were collected weekly for physicochemical analyses. Mass balance was performed on the inputs and outputs of the system carbon (C) and nitrogen (N). The entries were calculated based on the amount of N and C retained in the carcasses of the swine that entered the building, as well as the food consumed by the animals, using the equations proposed by CORPEN (2003). The outputs of elements C and N corresponded to those contained in the waste and carcasses of slaughtered animals.

The differences in the masses of C and N were considered as losses of these elements in the form of gases and the measured emissions of C- $\text{CH}_4$ , C- $\text{CO}_2$ , N- $\text{NH}_3$  and N- $\text{N}_2\text{O}$ , were considered, which represent the amounts of C and N in each gas, respectively.

The experimental design consisted of only one factor that corresponded to the method applied to determine the emission of gases, with two levels: a simplified method and the continuous method. As mentioned earlier, 144 animals were randomly distributed in 12 pens. Moreover, the evaluation time was considered as the number of replicates per treatment. A total of with 36 evaluation times (repetitions) were considered as the four gases as response variables ( $\text{CO}_2$ ,  $\text{CH}_4$ ,  $\text{N}_2\text{O}$ , and  $\text{NH}_3$ ).

The results thus obtained were subject to a preliminary analysis through the application of the Microsoft Excel® Software to eliminate the discrepant values and possible errors. To present the results, descriptive statistical analysis was performed to explore the data. Graphical elaboration of the results was performed using SigmaPlot® software. To evaluate the results obtained for the methodologies, the data were submitted to variance analysis using the PROC MIXED procedure of the SAS® statistical package. The comparison between continuous and simplified methodologies was performed using the Tukey's test for dependent samples, while Pearson's correlation test and  $\alpha$  were used to verify the associations and agreement between parameters. In all cases, the significance level was set at  $p \leq 0.05$ .

## RESULTS AND DISCUSSION

To produce one kilogram of pork produced under the given conditions, the average GHG and ammonia emissions are 2.2, 0.0002, 0.004 and 0.012 kg of  $\text{CO}_2$ ,  $\text{N}_2\text{O}$ ,  $\text{CH}_4$  and  $\text{NH}_3$ , respectively. These data were similar to those obtained by Ponchant et al. (2008) and Robin et al. (2013).

Several methods are available for determining the GHG emissions in swine farming. These methods include continuous and simplified methods discussed earlier. The advantage of the continuous method is the possibility of better characterization of emissions throughout the seasons, and it serves as a model for comparison with new methods, as it is considered the standard method. However, it has the disadvantage of high cost (Robin et al., 2013). The simplified method is more economical

and requires less time to obtain the results. Its disadvantages include variable characteristics according to time, climate, food, handling, as well as building characteristics, as most of them have natural ventilation, which makes it difficult to correctly determine the air flow, and consequently, the emission of gases (Guinand et al., 2011).

During the experiment, the minimum and maximum average values of air temperature, relative air humidity, and air velocity inside and outside the building were  $26.8 \pm 3.4$  and  $27 \pm 2.5$  °C, 70 and 80%, and 0.59 and 0.77 m s<sup>-1</sup>, respectively. These results indicate that the air temperatures observed were above the comfort range of the animals in the finishing phase, which can affect weight gain and feed conversion, as animals with heat stress spend more time lying down and consume less food. The ideal comfort temperature range for swine in terms of growth and termination rate for animals weighing over 25 kg is between 18 and 24 °C (Philippe & Nicks, 2015). Air temperatures above this range affect the zootechnical indices, such as weight gain and feed conversion; the higher the feed conversion, the lower the excretion, and consequently, the lower the emission of gases (Lima et al., 2022).

The data in Table 1 demonstrate the average data of gaseous emissions in (g per swine per day), obtained using simplified and continuous methods. A significant difference ( $p \leq 0.05$ ) was observed between these methods for all gases observed. According to Guinand et al. (2011), the simplified method can be used as a reliable and accurate method for measuring ammonia and greenhouse gases in finishing swine farms. There were differences of up to 80% between the values obtained from these two methods, and the simplified methodology quantified higher values than the continuous methodology for CO<sub>2</sub>, C-CO<sub>2</sub>, NH<sub>3</sub>, and N-NH<sub>3</sub>, mainly due to the variables of climate, wind, and temperature. These differences were greater than those obtained by Guinand et al. (2011) and Robin et al. (2013).

CO<sub>2</sub> values are important for calculating the minimum ventilation rates on a farm. The result obtained using the continuous method was 637.0 g per swine per day, which is lower than that obtained by Guinand et al. (2011), which is 676.0 g per swine per day. However, the result obtained by Tavares et al. (2014) for the same is 456.23 g per swine per

day, which is lower than that obtained using the simplified method. However, the difference between the values was lower in this case.

The N-NH<sub>3</sub> emission values obtained using the continuous and simplified methods were 4.81 and 11.76 g per swine per day, respectively. These values are higher than that found by Tavares et al. (2014), which was 3.04 g per swine per day. Whereas the values obtained by Guinand et al. (2011) for continuous and simplified methods are 8.9 and 10.8 g per swine per day. Compared to our results, these values are higher and lower in the case of continuous and simplified methods, respectively. This difference in the values may be due to the type of building and ventilation used because, in Brazil, most buildings are open and have natural ventilation; whereas in France, buildings are usually closed and with mechanical ventilation. Therefore, the NH<sub>3</sub> values can be justified because the farm has natural ventilation. The N-N<sub>2</sub>O emissions found by Tavares et al. (2014) were 0.24 g per swine per day, which is higher than those obtained using the simplified method and lower than that obtained using the continuous method. It is noteworthy that the obtained values showed less deviation in the case of simplified method than in the case of continuous method.

The values of C-CH<sub>4</sub> found by Guinand et al. (2011) using simplified and continuous methods were 7.4 and 10.1 g per swine per day; compared to the results of this research, these values are higher in the case of simplified method and lower in the case of continuous method. Moreover, both of these are lower than the result obtained by Tavares et al. (2014), which was 33.69 g per swine per day. C-CH<sub>4</sub> emissions were higher when compared to European results, which can be justified by the Brazilian temperature being higher and the experiment taking place in the summer period, with average temperatures ranging from 23.2 to 31.1 °C. Monitoring of gas emissions from swine farming is performed more frequently in Europe and North America. According to the European Environment Agency, swine production represents approximately 25% of emissions among other livestock activities (EEA, 2020).

Regarding the values obtained by the two methodologies studied, it is noted that there was a similar arrangement of the data as a function of time.

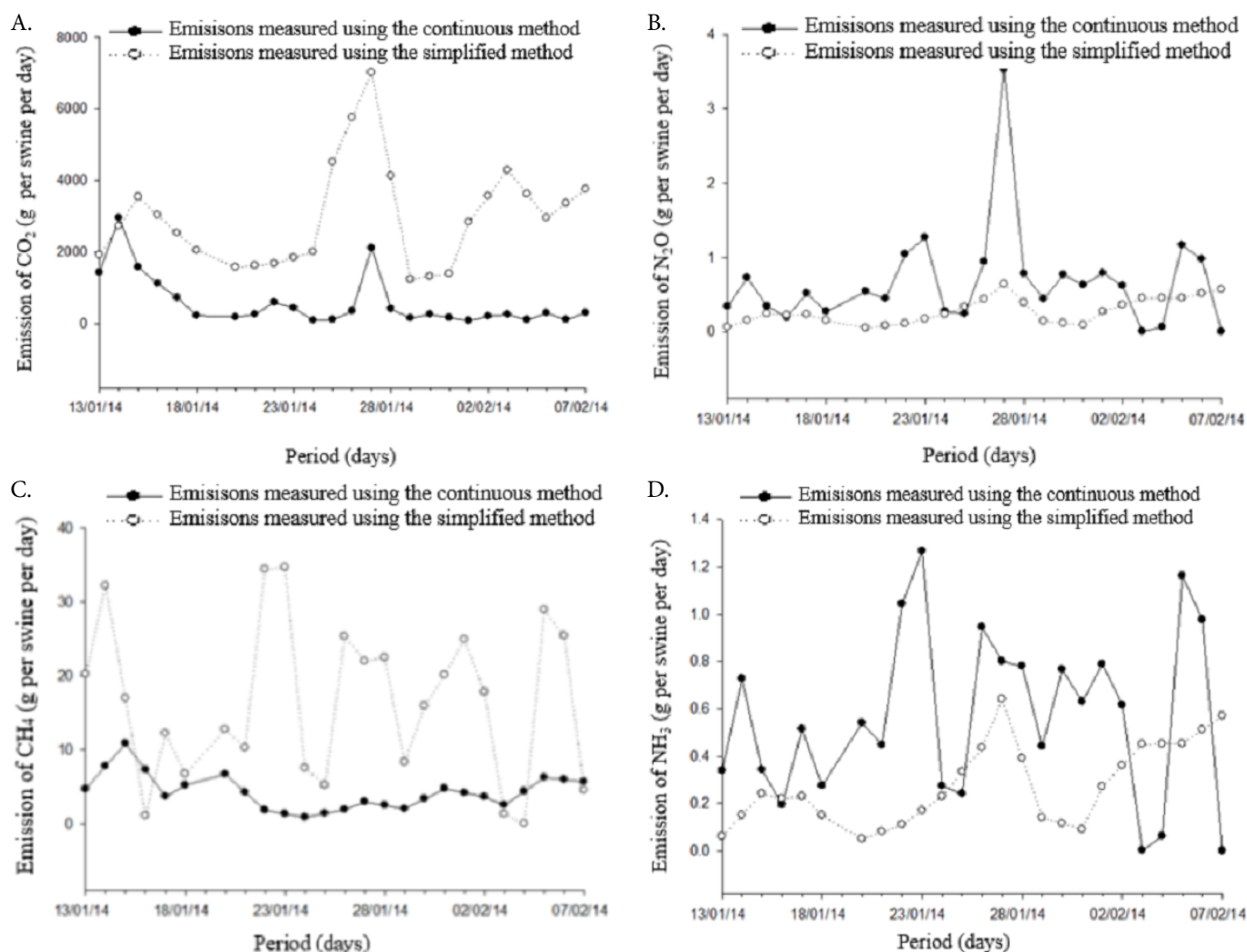
Peak CO<sub>2</sub> emissions occurred when the animals were fed (Figure 1A). However, in these periods, it was observed that the animals presented high agitation and competition to obtain food, which caused the activation of metabolism and, which consequently increased the release of CO<sub>2</sub> by respiration into the atmosphere. Su et al. (2019) conducted a study and found direct relationships on the level of animal activities and CO<sub>2</sub> emissions and added that gas emissions have been used to measure environmental pollution from a production viewpoint.

The differences in N<sub>2</sub>O (nitrous oxide) emissions were significant between the two methods; however, the percentage difference was between 30 and 50% (Figure 1B). According to Robin et al. (2013), the acceptable difference between the methodologies is 30%. Thus, this simplified methodology can replace the continuous quantification of N<sub>2</sub>O emissions, which showed a peak in gas production.

**Table 1.** Emissions of ammonia, nitrous oxide, methane, and carbon dioxide, obtained by continuous and simplified methods for swine in finishing phase

	Continuous method	Simplified method	CV (%)
Emissions			
CO <sub>2</sub> (g per swine per day)	575 b	2,680 a	20.04
NH <sub>3</sub> (g per swine per day)	5.89 b	13.5 a	13.99
N <sub>2</sub> O (g per swine per day)	0.68 a	0.29 b	8.45
CH <sub>4</sub> (g per swine per day)	19.50 a	4.38 b	11.31
Emissions			
C-CO <sub>2</sub> (g per swine per day)	157 b	768 a	5.34
N-NH <sub>3</sub> (g per swine per day)	4.81 b	11.76 a	3.09
N-N <sub>2</sub> O (g per swine per day)	0.43 a	0.19 b	14.31
C-CH <sub>4</sub> (g per swine per day)	14.60 a	3.3 b	12.44

Means with different letters in the same line differ from each other according to Tukey's test ( $p \leq 0.05$ ). CO<sub>2</sub> - Carbon dioxide; NH<sub>3</sub> - Ammonia; N<sub>2</sub>O - Nitrous oxide; CH<sub>4</sub> - Methane; C-CO<sub>2</sub> - Carbon present in carbon dioxide; N-NH<sub>3</sub> - Nitrogen present in ammonia; N-N<sub>2</sub>O - Nitrogen present in nitrous oxide; C-CH<sub>4</sub> - Carbon present in methane



**Figure 1.** Comparison of gaseous emissions obtained by continuous (MC) and simplified (MS) methods, for (A) carbon dioxide ( $\text{CO}_2$ ), (B) nitrous oxide ( $\text{N}_2\text{O}$ ), methane ( $\text{CH}_4$ ) (C) methane ( $\text{CH}_4$ ), and (D) ammonia ( $\text{NH}_3$ ), during the finishing phase

Microbial development is normally a function of the carbon and energy available in a medium, temperature, humidity, and pH, and the interactions between these factors regulate the nitrification activity. Thus, the peak  $\text{N}_2\text{O}$  production was observed during feeding periods, and the formation of nitrous oxide occurred during nitrification and denitrification in the manure present on the floor of the pens.

The data in Figure 1 demonstrate the gaseous emissions obtained using the simplified and continuous methods. For  $\text{N}_2\text{O}$  (Figure 1B), there was a smaller variation between the data obtained by the two methodologies during the observation period. The mean emission for  $\text{N}_2\text{O}$  was 0.30 and 0.67 g per swine per day in the case of simplified and continuous methods, respectively. In systems with slatted floors, nitrous oxide values ranged from 0.17 to 2.26 g per swine per day (Rigolot et al., 2010).

For  $\text{CH}_4$ , a significant variation was observed between the values obtained using the continuous method (Figure 1C). There was a significant difference ( $p \leq 0.05$ ) between the analyzed methods, and the percentage differences were considerable. The obtained  $\text{CH}_4$  concentrations indicated that there was a statistical difference ( $p \leq 0.05$ ) between the results obtained from different methods, as shown in Table 1.

A high correlation ( $p \leq 0.05$ ) was observed between methane and nitrous oxide using the continuous method.

This relationship may be a consequence of the organic decomposition present in the waste flow channels. It was observed that there was a large amount of waste accumulated at the site. According to Bernabé et al. (2020), even though the animals were housed in pens with forced ventilation and consumed a greater amount of feed, their nutritional content was consumed by their body to dissipate heat and maintain homeothermy, which resulted in a lower weight of the animals. Statistical analysis revealed significant differences ( $p \leq 0.05$ ), and the differences in percentage were considerable.

The  $\text{NH}_3$  concentrations obtained indicate that there is a statistical difference ( $p \leq 0.05$ ) between the results obtained from these methods (Figure 1D), with the results of  $\text{NH}_3$  content measurement performed using the continuous method being higher than those obtained using the simplified method. This occurs because in liquid waste (urine and feces), the nitrogen present in the urine is quickly converted to ammonia nitrogen (Philippe & Nicks, 2015) and, as waste accumulates inside the facility, it is expected that ammonia concentrations are higher than in the external environment. The results obtained for  $\text{NH}_3$  by Cao et al. (2020) for the summer phase were similar to those obtained in this study.

To verify the possible relationships between the amounts of emitted gases, correlation analysis was performed. The data in

**Table 2.** Pearson correlation coefficient between mean emissions of ammonia (NH<sub>3</sub>), nitrous oxide (N<sub>2</sub>O), methane (CH<sub>4</sub>), carbon dioxide (CO<sub>2</sub>), and water vapor (H<sub>2</sub>O) during the finishing phase, left: continuous method, and right: simplified method

	Continuous method				Simplified method			
	NH <sub>3</sub>	N <sub>2</sub> O	CH <sub>4</sub>	CO <sub>2</sub>	NH <sub>3</sub>	N <sub>2</sub> O	CH <sub>4</sub>	CO <sub>2</sub>
N <sub>2</sub> O	0.10	/	/	/	0.78	/	/	/
CH <sub>4</sub>	0.28	0.96	/	/	0.04	-0.07	/	/
CO <sub>2</sub>	0.92	0.37	0.51	/	0.96	0.81	0.07	/
H <sub>2</sub> O	0.29	0.40	0.39	0.46	0.74	0.45	0.15	0.80

Table 2 present the Pearson correlation coefficients (p) between the gas emission values measured using the continuous and simplified methods.

This result indicates that, in the simplified and continuous methods, ammonia emissions increased with the increase in carbon dioxide emissions (Table 2). A high correlation ( $p \leq 0.05$ ) was observed. According to Oliveira et al. (2019), this high correlation may occur due to the increased respiratory rate of the animal when exhaling excess ammonia present in the environment.

The data in Table 3 demonstrate the total carbon and nitrogen emissions measured using the continuous and simplified methods compared with the mass balance. The total carbon emissions obtained by the simplified method corresponded to 2.919 kg, referring to the total experimental period, as well as the batch of animals. When compared to the total carbon obtained by mass balance (617.59 kg), a difference of approximately 2% was found, which indicates sufficiently accurate measurement of carbon emissions in swine production systems, and the simplified methodology proved to be more efficient (Ponchant et al., 2008; Robin et al., 2013).

The value obtained by the nitrogen mass balance also considers molecular nitrogen (N<sub>2</sub>). This form of nitrogen goes undetected when using sensors of the INNOVA gas analyzer. According to Ponchant et al. (2008), molecular nitrogen can correspond 30 to 60% of volatilized nitrogen.

The total nitrogen emissions obtained by the simplified method corresponded to 45.72 kg for the breeding period. When compared to the values obtained by mass balance, it was found that the difference was approximately 14%, which is considered acceptable by Ponchant et al. (2008) and Guingand et al. (2011). The data obtained using the continuous method was found to differ significantly from that of the mass balance method; the differences were greater than 80%, which is above the acceptable limit (Ponchant et al., 2008; Robin et al., 2013).

The data in Table 4 show the emissions of CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub>, and NH<sub>3</sub>, referring to the production of a swine with an average weight of 115 kg, and the relationship between pork production and gas emissions per kg of carcass.

Statistical analysis revealed significant differences ( $p \leq 0.05$ ). As shown in Table 4, it can be noted that production of a swine with an average weight of 115 kg results in average emissions of 252.8, 0.030, 0.413 and 1.3 kg of CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub> and NH<sub>3</sub>, respectively.

**Table 3.** Comparison of measured values of total carbon and nitrogen emissions during the finishing phase in the case of continuous (MC), simplified (MS), and mass balance methods

Element	MC emissions	MS emissions	Mass balance
	(kg)		(Deficit kg)
Carbon	617.59	2.919. 00	2.868.00
Nitrogen	18.86	45.72	133.5*

\*30-60% of this value corresponds to molecular nitrogen

**Table 4.** Emission data of carbon dioxide (CO<sub>2</sub>), nitrous oxide (N<sub>2</sub>O), methane (CH<sub>4</sub>) and ammonia (NH<sub>3</sub>) referring to the production of a swine with an average weight of 115 kg and the production of per kg of carcass

Gas	Gas emission (kg gas per swine)	Gas emission (kg gas per kg of carcass)
Carbon dioxide (CO <sub>2</sub> )	252.8	2.2
Nitrous oxide (N <sub>2</sub> O)	0.03	0.0002
Methane (CH <sub>4</sub> )	0.4	0.004
Ammonia (NH <sub>3</sub> )	1.3	0.012

Data from the simplified methodology

However, considering the gaseous emission in relation to meat production, it can be said that to produce a kilogram of pork, a certain volume of polluting gases is sent to the atmosphere. Production of one kilogram of pork under these conditions, results in average emissions of 2.2, 0.0002, 0.004, and 0.012 kg of CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub>, and NH<sub>3</sub>, respectively. These results are similar to those obtained by Ponchant et al. (2008) and Robin et al. (2013).

## CONCLUSIONS

1. The emission flow obtained using the simplified method in [g per swine h<sup>-1</sup>] was of 2.689 for carbon dioxide (CO<sub>2</sub>), 0.30 for nitrous oxide (N<sub>2</sub>O), 4.39 for methane (CH<sub>4</sub>), 13.55 for ammonia (NH<sub>3</sub>), and 3.273 for water vapor, whereas that obtained using the continuous method in [g per swine h<sup>-1</sup>] was of 574 for CO<sub>2</sub>, 0.67 for N<sub>2</sub>O, 19.50 for CH<sub>4</sub>, 5.84 for NH<sub>3</sub>, and 7.2 for water vapor.

2. The simplified method developed in this study is more effective for estimating GHG emissions in swine farming systems with natural ventilation compared to the continuous method. Moreover, it was verified based on mass balance.

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