

## TECHNICAL NOTE: A FLUX CHAMBER FOR MEASURING GAS EMISSIONS FROM RABBITS

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**ABSTRACT:** Atmospheric pollution related to gas emissions from livestock production has become an issue of increasing interest. International commitments bind countries to provide annual reports on national emissions, however there is a lack of information regarding the estimation of emissions from rabbit farms. There are several methodologies available to measure gas emissions, the flux chamber technique being one of the most commonly used. In this study, a flux chamber was designed to measure emissions from small farm animals and their manure, as well as the methodology to calculate ventilation fluxes appropriate for each experiment. After the chamber was constructed, two experiments were carried out to test its operation, design and construction. Firstly, carbon dioxide emissions from fattening rabbits were measured for 24 and 48 h. Emissions from fattening rabbit manure were then measured for one-hour periods. The operation of the flux chamber was satisfactory during both experiments and notes were taken of possible improvements in performance through future research. Recommendations for its use are also summarized.

**Key Words:** rabbits, gaseous emissions, ammonia, carbon dioxide, flux chamber.

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### INTRODUCTION

Ammonia and greenhouse gas emissions currently constitute one of the main environmental problems for livestock production (Owen, 1994). For some years international agreements (e.g. Kyoto Protocol, 1998 and European Council, 2000) have required countries to report total emissions of greenhouse gases and ammonia and to take steps to reduce their volume. National emissions inventories are thus crucial to achieving these two goals.

In order to compile national inventories of the livestock production sector, accurate data are needed to calculate the amount of gases produced. Information is frequently unavailable for gas emissions from certain animal sources, for example those from species typically reared in the Mediterranean area. Rabbit production is one area in which there are little data related to ammonia and greenhouse gas emissions.

The two main sources of gas emissions from livestock production are manure and enteric fermentation (IPCC, 2006). On the one hand, manure is the primary source of ammonia and nitrous oxide emissions, as well as a critical source of methane and carbon dioxide. There are many studies on gas emissions from

the manure of many animal species (e.g. Wathes *et al.*, 1998), but to our knowledge, no data are available on rabbit manure.

Large amounts of methane and carbon dioxide are also emitted as a result of the enteric fermentation process. These processes are crucial in ruminants and therefore constitute the primary source of these gases. However, it is generally accepted that some monogastric animals, such as pigs, horses or rabbits, also produce significant amounts of these gases from their digestion processes (Crutzen *et al.*, 1986).

As hindgut fermenters (Langer, 2002), rabbits produce considerable amounts of methane during digestion, mainly due to anaerobic decomposition reactions in the caecum. Although experiments have evaluated methane production using caecum cultures *in vitro* (Piattoni *et al.*, 1996), there is little information available on living animals and these data are not useful in estimating total methane emissions from farmed rabbits.

Taking into account the increasing number of rabbits reared in Mediterranean countries, their methane emissions should be considered and included in national gas inventories. Experimental measurements are therefore essential to obtain estimations for rabbits and complete these gas emission inventories (IPCC, 2006).

Several methods are available to assess animal gas emissions. Ni and Heber (2008) provided a comprehensive review of the most widespread methodologies used to measure these emissions: static chambers, dynamic chambers, tracer methods and micrometeorological techniques. Static chambers are generally used to measure emissions from manure, whereas dynamic chambers are useful to measure emissions from both manure and animals. Tracer methods can be used to measure emissions from buildings and, in some cases, to quantify methane emissions from large animals (ruminants). Finally, micrometeorological techniques are widely used to obtain open-range emission data (Misselbrook *et al.*, 2005).

Chambers offer four advantages: easy replication, comparison of treatments, there are no site restrictions and are relatively inexpensive (Shah *et al.*, 2006b). The chambers usually enclose a small area (0.1 to 0.2 m<sup>2</sup>), which may be a restriction when studying heterogeneous emitting sources, for example, open field emissions (Meissinger *et al.*, 2001).

The emissions from a dynamic chamber can be calculated according to the mass conservation law, which may be simplified for a stationary state as shown in Equation 1:

$$E = (C_{inlet} - C_{outlet}) \times Flux \quad \text{Equation 1}$$

Where:

E: Emission rate (mg·h<sup>-1</sup>).

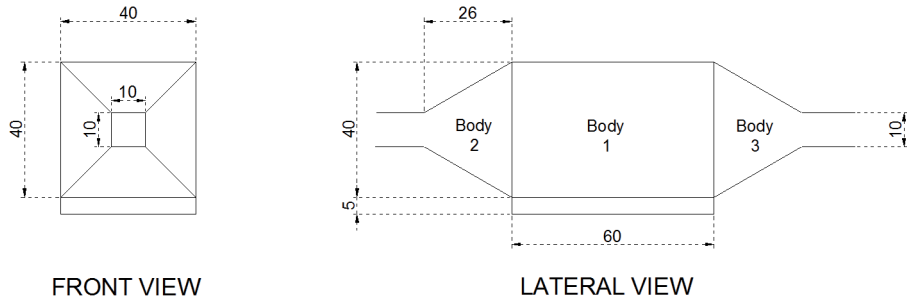
C<sub>inlet</sub>: Inlet gas concentration (mg·m<sup>-3</sup>).

C<sub>outlet</sub>: Outlet gas concentration (mg·m<sup>-3</sup>).

Flux: Airflow exchange in the chamber (m<sup>3</sup>·h<sup>-1</sup>).

Dynamic chambers have been developed primarily to study emissions from large animals, such as sheep (Blummel *et al.*, 2005) and cattle (Beauchemin and McGinn, 2005; Kurihara *et al.*, 1999). These chambers have also been used to estimate poultry emissions (Wang and Huang, 2005). Kiwull-Schöne *et al.* (2001, 2005) used these chambers for nutritional studies with rabbits. Dynamic and static chambers are thus considered as robust methods of measuring emissions from both animals and their manure.

This research is aimed at adapting, designing and testing a flux chamber for small animals, principally rabbits, so as to accurately compile data for emissions from both the animals and manure. The standard



**Figure 1:** Schema of the chamber (measurements in cm).

methodology for its use will be described and basic recommendations will be provided. Obtaining experimental data on rabbit greenhouse gases and ammonia emissions will contribute to completing national emissions inventories and, subsequently, to implementing strategies to reduce the emissions themselves.

## MATERIALS AND METHODS

### *Chamber design*

The basic structure of the chamber (60 cm long  $\times$  40 cm wide  $\times$  40 cm high) was made with polymethyl methacrylate (PMMA) (0.5 cm thick). The chamber did not have a base and was designed to be placed on a flat surface where it self-sealed with rubber. The air inlet and outlet passed through two lateral modules in the shape of a pyramid, finishing in a cube (10 $\times$ 5 $\times$ 5 cm), also made of PMMA. Figure 1 shows the construction and shape of the chamber. The total volume of the chamber was 0.1705 m<sup>3</sup>, and the base covered an area of 0.24 m<sup>2</sup>.

### *Flow rate*

Gas emissions are directly conditioned by flow rate, as indicated in Equation 1. Therefore, one of the main considerations when designing a chamber is to choose an appropriate flow rate. In addition, the air exchange rate directly influences the environmental conditions inside the chamber, such as relative humidity (RH) and temperature (t). For this reason, the ventilation flow required is different for the two possible emitting sources (animals or manure) and should be established during the experimental design. The main factors to be considered when calculating airflow requirements are i) emission source needs, ii) environmental conditions and iii) the sensor used to measure gas concentration.

i) Emission source needs. The optimal ventilation flow depends mainly on temperature, humidity and the carbon dioxide concentration produced by the animals themselves through metabolism. Proper ventilation flow will prevent inadequate environmental conditions inside the chamber. When measuring animal emissions, ventilation flow should be calculated considering these three factors, by means of Equations 2, 3 and 4, respectively. Finally, the highest ventilation flow will be chosen to account for the most restrictive factor.

$$V_{CO_2} (m^3 \cdot h^{-1}) = \frac{E_{CO_2}}{CO_{2 \max} - CO_{2 \text{out}}} \quad \text{Equation 2}$$

Where:

- $V_{CO_2}$ : Flux to eliminate excess carbon dioxide ( $m^3 \cdot h^{-1}$ ).
- $E_{CO_2}$ : Carbon dioxide emission ( $mg \cdot h^{-1}$ ).
- $CO_{2\max}$ : Maximum  $CO_2$  concentration admissible for the animal ( $mg \cdot m^{-3}$ ).
- $CO_{2out}$ : Carbon dioxide concentration of external air ( $mg \cdot m^{-3}$ ).

$$V_{H_2O} (m^3 \cdot h^{-1}) = \frac{Q_l}{597 \times (w_i - w_o)} \times v_s \quad \text{Equation 3}$$

Where:

- $V_{H_2O}$ : Flux to eliminate excess humidity ( $m^3 \cdot h^{-1}$ ).
- $Q_l$ : Latent heat production ( $kcal \cdot h^{-1}$ ).
- $w_i$ : Internal air absolute humidity ( $kg \text{ water vapour} \cdot kg \text{ dry air}^{-1}$ ).
- $w_o$ : External air absolute humidity ( $kg \text{ water vapour} \cdot kg \text{ dry air}^{-1}$ ).
- $v_s$ : Specific volume of air ( $m^3 \cdot kg \text{ air}^{-1}$ ).
- 597: Energetic value of water vapour ( $kcal \cdot kg \text{ water vapour}^{-1}$ ).

$$V_{Heat} = (m^3 \cdot h^{-1}) = \frac{Q_s}{H_s \times (t_i - t_o)} \times v_s \quad \text{Equation 4}$$

Where:

- $V_{Heat}$ : Flux to eliminate excess heat ( $m^3/h$ ).
- $Q_s$ : Measured heat production ( $kcal/h$ ).
- $H_s$ : Specific heat of air ( $kcal/Kg \cdot ^\circ C$ ).
- $t_i$ : Internal air temperature ( $^\circ C$ ).
- $t_o$ : External air temperature ( $^\circ C$ ).
- $v_s$ : Specific volume of air ( $m^3/kg \text{ air}$ ).

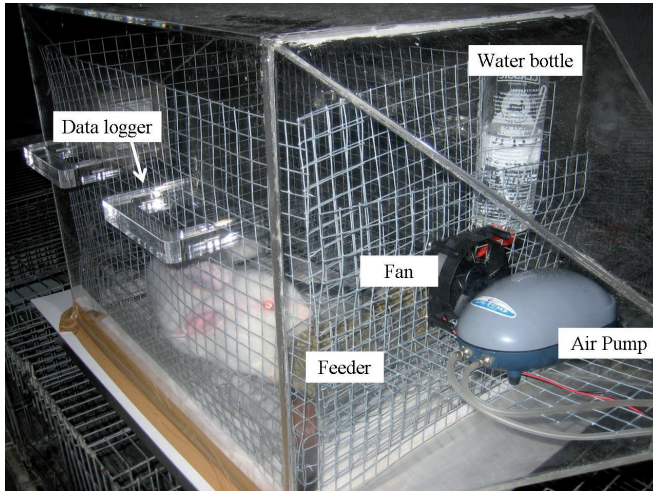
ii) Environmental conditions. Temperature and humidity inside the chamber can significantly affect manure and animal emissions and, as stated before, the air flow rate modifies the environmental conditions. Therefore, ventilation inside the chamber should aim to obtain environmental conditions similar to those existing in the animal rearing houses.

iii) Sensor used. It is necessary to consider the properties of the sensor used to measure gas concentrations. To determine an appropriate ventilation rate for the sensor two factors must be considered. The first consideration is sensor measuring range for each gas, which will determine the concentrations that can be measured in the chamber. Secondly, it is necessary to estimate the approximate emission rate expected for each gas. Equation 5 shows the calculation process for the ventilation rate according to the sensor measuring range.

$$C_{low} \leq \frac{E}{Flux} + C_{inlet} \leq C_{up} \quad \text{Equation 5}$$

Where:

- $C_{low}$ : Lower threshold of the sensor ( $mg \cdot m^{-3}$ ).
- $C_{up}$ : Upper threshold of the sensor ( $mg \cdot m^{-3}$ ).
- $E$ : Expected emission factor ( $mg \cdot h^{-1}$ ).
- $Flux$ : Air flux in the chamber ( $m^3 \cdot h^{-1}$ ).



**Figure 2:** Photo of the chamber during animal emissions experiment.

To sum up, one of the main considerations in establishing the ventilation flow with manure as the emission source is the sensor measurement range (Equation 5). On the other hand, when animals are studied, their environmental needs must be taken into account (Equations 2, 3 and 4), in addition to the sensor measurement range (Equation 5).

#### *Experimental tests*

To test the performance of the designed chamber, two experiments were carried out. In the first experiment, carbon dioxide emissions from fattening rabbits were measured over 4 d. In the second experiment, ammonia and carbon dioxide emissions from manure were measured during three periods of approximately one hour each.

#### *Carbon dioxide emissions from rabbits*

In the first experiment, the chamber was placed in an experimental rabbit farm located at the Universidad Politécnica de Valencia (Valencia, Spain). Inside the chamber the following devices were installed: an air pump for ventilation (Resun®Silent-Pump AC-9002,  $0.423 \text{ m}^3 \cdot \text{h}^{-1}$ ), a small fan to circulate the air inside the chamber (Power Logic PL80S12M), a water dispenser and a feeder. Outside the chamber a carbon dioxide sensor was placed (Vaisala GMT-222, 0-10,000 ppm), connected by means of a process adaptor (Vaisala 26150GM) to one of the exhaust tubes of the chamber. Data were recorded every minute with a data logger (HOBO H8 RH/Temp/Out, Onset Computer Corp., Pocasset, Mass.). Environmental conditions, including temperature and relative humidity, were measured using two data loggers (HOBO H8 RH/Temp, Onset Computer Corp., Pocasset, Mass.), one inside the chamber and the other outside. The chamber is assembled as depicted in Figure 2.

Three 32 d old (one week after weaning) crossbreed rabbits were selected for the study. The first experiment was designed as follows. During the first and second day, two of the three rabbits were placed in the chamber, individually, for 24 h each (Trial-1 [24 h] and Trial -2 [24 h]). The third rabbit (Trial-3) was placed in the chamber during the third and fourth day (48 h). This design allowed the study of the relative effect of the experimental period, particularly manure accumulation. Rabbits were weighed at the beginning and at the end of each trial. The feeder and water dispenser were also weighed to assess feed and water consumption. The data on rabbit performance for the different trials are summed up in Table 1.

**Table 1:** Rabbit growth in relation to water and feed consumption during the experiment.

Animal (id)	Initial age (d)	Entrance date	Duration (h)	Initial weight (kg)	Final weight (kg)	Water consumption (L)	Feed consumption (kg)
55531	32	6/08/07	24	0.980	1.040	0.220	0.080
56124	33	7/08/07	24	0.700	0.760	0.120	0.070
55304	34	8/08/07	48	0.780	0.860	0.180	0.150

Emissions were calculated on an hourly basis, using the general mass balance equation corrected by the metabolic weight (Equation 6):

$$E_{MW} = \frac{(C_{outlet} - C_{inlet}) \times Flux}{LW^{0.75}} \quad \text{Equation 6}$$

Where:

$E_{MW}$ : Emissions per metabolic weight ( $\text{mg} \cdot \text{LW}^{-0.75} \cdot \text{h}^{-1}$ ).

LW: Live weight (kg).

According to the expected relationship between carbon dioxide emissions and metabolic activity, emissions were corrected by dividing them by the metabolic weight of the animals. To minimise the effect of temperature, emissions were standardized at 20°C using the CIGR algorithm (Equation 7) to correct total heat production (CIGR, 2002), in which T is the measured temperature (°C).

$$\text{Conversion factor} = [1 + 4 \times 10^{-5} \times (20 - T)^3] \quad \text{Equation 7}$$

To determine the daily variation pattern, emissions were standardized by dividing each value by the global mean, thus obtaining the relative emission for each measurement.

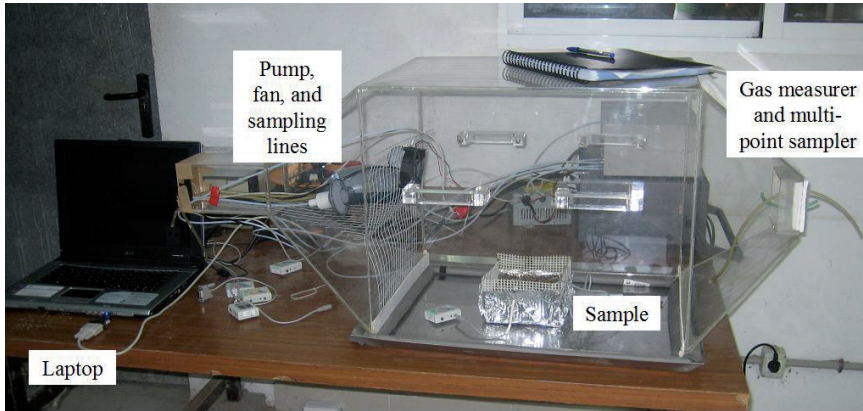
Mean emissions were obtained using PROC MEANS of SAS (SAS, 2002). Daily variation of these data was studied and modelled by means of PROC NLIN of SAS (SAS, 2002).

#### *Emissions from manure*

Three manure samples were taken from the experimental rabbit farm located in the Universidad Politécnica de Valencia (Valencia, Spain). Manure was sampled from the manure pits under the cages using three small boxes (15×15×5 cm) made with a mesh (4×4 mm orifices) that had been in the pits for one week. The sampling boxes were taken from the pit after the collection period and left on the ground to drain for approximately 15 min. The sides and base of the boxes were sealed with aluminium foil to prevent gas loss, so that emissions only flowed from the top surface. They were then individually placed in the chamber for approximately one hour. After each measuring period, the chamber was allowed to air for 30 min.

An air pump for ventilation (Resun®Silent-Pump AC-9002,  $0.552 \text{ m}^3 \cdot \text{h}^{-1}$ ) and a small air circulation fan (Power Logic PL80S12M). were placed inside the chamber. A multi-point sampling device was used to measure inlet and outlet gas concentrations in duplicate. Gas samples passed through Teflon tubes to a photoacoustic gas monitor (INNOVA 1412, AirTech Instruments), which measured gas concentrations ( $\text{NH}_3$  and  $\text{CO}_2$ ) at 2 min intervals. Average values for each location were then used to calculate the emissions. The assembled chamber is depicted in Figure 3.





**Figure 3:** Photo of the chamber containing rabbit manure.

Emissions were calculated with the simplified mass balance equation in a stationary state using Equation 1. It should be emphasised that for the first few minutes of measurement the chamber is subjected to a transitory regime. During this time, the concentration increases progressively from the initial value until it becomes stable, and only then can the emission be modelled as a stationary regime. In practice, it can be considered that the stationary regime is achieved when 95% of the equilibrium concentration is reached at the time given by Equation 8.

$$t = - \frac{V \cdot \ln(1 - 0.95)}{\text{Flux}} \quad \text{Equation 8}$$

Where:

t: Time to achieve a practical equilibrium in the chamber (h).

V: Chamber volume (m<sup>3</sup>).

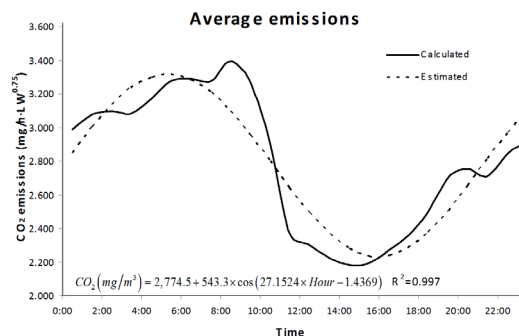
Flux: Air exchange rate (m<sup>3</sup>·h<sup>-1</sup>).

## RESULTS AND DISCUSSION

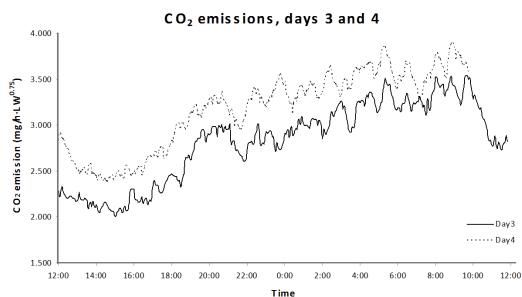
### *Experimental test 1 (animal emissions)*

Table 1 shows the productive results obtained during the three trials in terms of animal age, initial and final weight, as well as water and feed consumption. These results were similar to those obtained at the same experimental farm by Calvet *et al.* (2008) in a previous study. It may therefore be concluded that the animals were not affected by the chamber in terms of productive results.

The average carbon dioxide emission was 1.42±0.13 (L CO<sub>2</sub>·h<sup>-1</sup>·LW<sup>-0.75</sup>). This is a higher value than those reported by Kiwull-Schone *et al.* (2001, 2005), which were 0.825 and 0.935 L CO<sub>2</sub>·h<sup>-1</sup>·LW<sup>-0.75</sup>, respectively. This difference could be the result of the different methodology employed. In the latter case, animal emissions were only measured during a 25 min period, while in our experiment a longer period was used. In addition, no information was provided about the time when the experiment was carried out, as if measurements were taken during the day, lower emissions can be expected. It is also higher than the value estimated according to the CIGR (2002) methodology, which is about 1 L CO<sub>2</sub>·h<sup>-1</sup>·LW<sup>-0.75</sup>. It is important to make clear at this point that CIGR values are estimated and not measured, and this could be the cause of the difference observed. A daily pattern of CO<sub>2</sub> emissions was identified, as reflected in the



**Figure 4:** Average emissions and regression values.



**Figure 5:** Comparison of emissions, days 3 and 4 (Trial 3).

average hourly emissions graph (Figure 4). Emissions were higher during the night and early morning. During the third trial, the same emission pattern was observed, although higher emissions were observed during the second day than the first (Figure 5). It can thus be concluded that a 24 h period is long enough to determine the daily emission pattern. The higher emission values observed during the second day could be attributed to the accumulation of faeces in the chamber and the consequent increase of emissions from this source.

Ventilation flux was previously calculated using the Equations 2, 3, 4 and 5. Environmental conditions considered for the estimations were: outside air about 26°C and 50% RH (normal data for this period in Valencia), the highest desirable temperature and RH inside the chamber, calculated according to CIGR recommendations (1992), were 30°C and 60% RH. Values for CO<sub>2</sub>, and heat emissions were taken from CIGR (2002), as well as maximum CO<sub>2</sub> concentration for the animals and CO<sub>2</sub> concentration in the inlet air. Ventilation flows were estimated as 0.078 m<sup>3</sup>·h<sup>-1</sup>, 0.074 m<sup>3</sup>·h<sup>-1</sup> and 0.009 m<sup>3</sup>·h<sup>-1</sup> from the Equations 2, 3 and 4, respectively. According to the sensor measurement range (0-10,000 ppm) and the expected emission rate (0.060 m<sup>3</sup>·h<sup>-1</sup>, CIGR, 2002), the estimated ventilation flow range appropriate for this sensor, calculated by Equation 5, was in the order of 0.18 to 3.60 m<sup>3</sup>·h<sup>-1</sup>.

The temperature inside the chamber was similar to that registered in the building and ranged between 23°C and 31°C. Relative humidity was significantly higher inside the chamber than outside, reaching air saturation during the coldest periods. This indicates that previous estimations of air flux were not enough to prevent condensation, although the ventilation rate used in this experiment (0.423 m<sup>3</sup>·h<sup>-1</sup>) was clearly higher than the one estimated according to environmental requirements (0.078 m<sup>3</sup>·h<sup>-1</sup>).

Finally, it was observed that rabbits needed about one hour to become accustomed to the chamber; the exploratory activity resulting in higher emissions during this time. According to the results obtained in this research, values from this first hour should be disregarded.

#### *Experimental test 2 (manure emissions)*

Measured gas concentrations of ammonia and carbon dioxide ranged between 0.25 and 7 mg·m<sup>-3</sup> and 737 and 1,238 mg·m<sup>-3</sup>, respectively. In these terms, the ventilation flow selected for this study was appropriate for the measuring range of the gas analyser (0-50 mg·m<sup>-3</sup> NH<sub>3</sub> and 0-10,000 mg·m<sup>-3</sup> CO<sub>2</sub>).

Calculated emission values for the three trials were 3.26±0.01, 2.95±0.15 and 3.07±0.01 mg NH<sub>3</sub>·h<sup>-1</sup> and 216.9±0.3, 219.2±2.8 and 272.4±0.2 mg CO<sub>2</sub>·h<sup>-1</sup>, respectively.



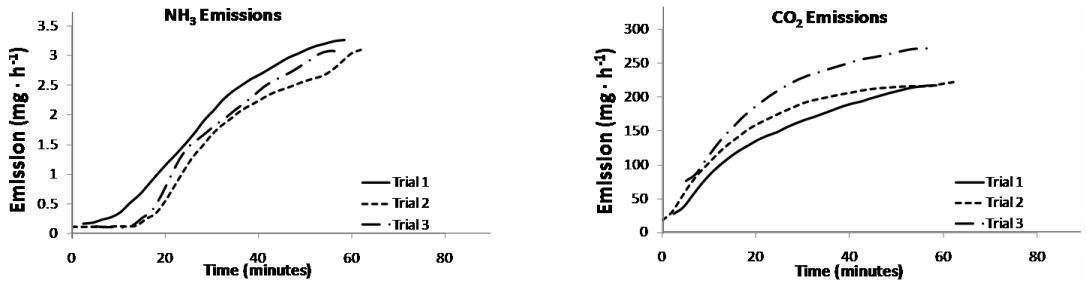


Figure 6: NH<sub>3</sub> and CO<sub>2</sub> emissions from rabbit manure.

The evolution of measured ammonia and carbon dioxide emissions is depicted in Figure 6. Emissions increased continuously during the first minutes, due to the transitory regime in the chamber. Fifty-five minutes were needed to achieve the stationary regime in the chamber, calculated using Equation 8. In practice, it was observed that the stationary regime had not been completely reached after 55 min, and therefore, a longer measuring period would be necessary when using the same chamber set-up. As an alternative solution, increasing the ventilation rate would reduce the length of the transitory regime.

The chamber performance was satisfactory, particularly in characterising emissions from rabbits. If the objective were to measure emissions from manure, a smaller chamber would be preferable for two reasons: firstly, smaller dimensions would facilitate operations; and secondly, the transitory regime would be shorter according to Equation 6.

#### *Chamber design and operation*

From the results obtained in these trials, several advantages were noted regarding the chamber design and operation.

The material (PMMA) used is resistant (suitable for farm conditions), light enough to be handled easily and is transparent, so that animals can see through it. Furthermore, as it is used indoors, temperature is not affected by solar radiation (Shah *et al.*, 2006b). A chamber with these characteristics may thus be deemed appropriate to measure emissions from animals and manure.

Regarding to the cost of the chamber, it is widely accepted that dynamic chambers are among the cheapest methods of measuring emissions from point-sources like animals or small manure surfaces (Farrell, 1972; Shah *et al.*, 2006a). However, the cost can vary considerably, depending on the accessories used, especially the air pump, fan and gas analyzers.

The chamber described herein was appropriate to measure animal emissions, according to the morphology and size, and was similar to that used for poultry by Wang and Huang (2005). The surface area available for each animal inside the chamber (2,400 cm<sup>2</sup>) is larger than those found in commercial farms, which range between 400 and 700 cm<sup>2</sup> (Trocino and Xiccato, 2006). The cage height (40 cm) is similar to common commercial cages, which vary between 30 and 40 cm (Trocino and Xiccato, 2006). The chamber design was also appropriate to determine manure emissions, and the surface area is similar to others used previously (Blanes-Vidal *et al.*, 2007; Boriack, 2005; Skiba *et al.*, 2006). However, as there are no clear recommendations in the literature concerning the shape of the chamber and manure emissions, this is probably not a highly determining factor.

## CONCLUSIONS

Dynamic chambers are extremely useful to measure greenhouse gas and ammonia emissions from animal production.

When using the chamber to measure rabbit emissions (e.g. CO<sub>2</sub>, CH<sub>4</sub>), a 24 h period is recommended to allow for the daily variation in gas emissions from animals. To avoid excessive emissions from this source, longer measuring periods are not recommended unless faeces and urine are extracted from the chamber. It is also necessary to consider the period of animal adaptation to the chamber, in which emissions are not representative. According to the findings, an adaptation period of approximately 1 hour should be established. A ventilation flux of 0.423 m<sup>3</sup>·h<sup>-1</sup> fulfils most animal needs, although high relative humidity levels are reached. Higher ventilation flows are therefore recommended to avoid condensation of water vapour. This is a crucial issue if ammonia concentrations are also being measured, due to the ability of this gas to mix with water and condense, which would cause a decrease in ammonia concentration.

To measure manure emissions (NH<sub>3</sub> and CO<sub>2</sub>), the chamber used in this study performed satisfactorily. However, the use of a smaller chamber would reduce measuring time and make the operation easier. The chamber airflow rate, however, cannot be previously established for all experiments as it depends on the emitting potential of the manure and must be specifically determined for each experiment.

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