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USE OF CARBON DIOXIDE BALANCES TO DETERMINE VENTILATION RATES FROM FATTENING RABBITS FARMS

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ABSTRACT Determining accurately the ventilation rates in livestock houses is a crucial factor when measuring airborne emissions. Methods to determine these ventilation rates can be classified in two groups: direct and indirect methods. One of the most spread indirect methods to determine ventilation rates in livestock houses is the CO_2 balance. When using this method data on CO_2 concentrations in the inlet and outlet air of the farm as well as the carbon dioxide release rate for the animals and manure are needed to calculate the ventilation rate. This method has been successfully used before in poultry, cattle and pig farms, but not yet in rabbit farms. Thus, the aim of this work is to test the carbon dioxide balance as a method to determine the ventilation rate in fattening rabbit farms. Two fattening rabbit farms were evaluated during this work. CO_2 concentrations were simultaneously determined in the inlet and outlet air by using a photoacoustic monitor. Ventilation rates were also determined by calibration of the exhaust fans and monitoring their performance. Carbon dioxide emissions from the animals and also from their manure were determined using experimental values. Ventilation rates were determined by using the general equation of CO_2 balances and compared with direct measurements. Results obtained showed a deviation between measured and estimated ventilation rates. The carbon dioxide balance overestimated the measured ventilation flow at about 30%. According to these results, further research is needed to improve these CO_2 balances.

Keywords: CO_2 balances, ventilation rate, fattening rabbits.

INTRODUCTION

The intensive rearing of rabbits for meat production is a specialised farming activity in certain countries, most of them located in the Mediterranean area. Several studies have been carried out in order to study rabbit management, nutrition and genetics but the environmental pollution impact of this activity is not well known. In this sense, few publications can be found related to airborne emissions from rabbit farms (Hol *et al.*, 2004; Michl and Hoy, 1996).

Airborne emissions from livestock facilities are usually estimated by means of mass balances. In these balances the difference between incoming and outgoing matter fluxes for the building measured is defined as the emission rate.

To determine these incoming and outgoing matter fluxes, two factors are needed: mass concentrations and airflow rates. The measurement of gas, dust and odour concentrations can be achieved, with adequate accuracy, by using a variety of techniques (Chen *et al.*, 1999; Ni and Heber, 2008). On the contrary, measuring the airflow in an animal house is one of the main challenges that can be found to estimate these emissions. Airflow rates can be determined using several methods. According to Phillips *et al*. (2001) they can be classified in two main groups regarding to their nature: indirect and direct measurement methods. The first one consists of using a tracer, which allows us to determine the ventilation flux both in mechanically and naturally ventilated houses. Direct measurement methods consist of determining the airflow rates through all openings in a building. This second group of techniques is generally more accurate, but they can be used only in mechanically-ventilated houses and when all openings of the farm can be assessed.

When measuring airborne emissions from commercial livestock buildings, direct airflow measurements are difficult to apply in practice. As explained before, these methods cannot be applied in naturally-ventilated buildings but even in mechanically-ventilated ones, sometimes this technique cannot be applied, due to the technical difficulties associated, e.g. calibrating the fans may disturb their normal operation procedure. Even it is if possible, this task is time-consuming (Pedersen *et al.*, 1998).

Indirect methods arise then as a useful alternative, which allow us to determine airflow rates in most situations. The principle of the method is to monitor the inlet and outlet concentrations of a tracer gas with a known release rate. The airflow can then be calculated by applying a mass balance. The ideal characteristics of a tracer include low and stable background level, no hazard, acceptability, ease of measurement, stability and low cost (Phillips *et al*., 2001). Carbon dioxide, which is emitted naturally on the farm, fulfils all these characteristics, and consequently, carbon dioxide balances have been commonly used in Europe to determine the ventilation rates in livestock buildings (Pedersen et al., 1998).

Carbon dioxide balances development

Considering mass conservation under steady state conditions in the building, the general equation for the carbon dioxide balance can be expressed as follows (Equation 1):

$$V_{CO_2} = CO_{2rel} \left(CO_{2outlet} - CO_{2inlet} \right)^{-1} N^{-1} \quad (1)$$

Where:

V_{CO2}: Ventilation flux per animal estimated through CO_2 balance ($m^3\ h^{-1}\ animal^{-1}$)

CO_{2rel}: Carbon dioxide release rate in the building ($mg\ h^{-1}$)

$CO_{2outlet}$: Carbon dioxide concentration in the outlet ($mg\ m^{-3}$)

CO_{2inlet}: Carbon dioxide concentration in the inlet (mg m^{-3})

N: Number of animals in the farm

Therefore, to develop these CO_2 balances it is necessary to know the amount of carbon dioxide that is being released in the building (CO_{2rel}). There are two sources of CO_2 in an animal house, most of the carbon dioxide that is being released in the building is originated by the animals during respiration processes while the rest is originated from the decomposition of manure (van Ouwerkerk and Pedersen, 1994) After a comprehensive literature review (CIGR, 2002), carbon dioxide emission rates have been provided for most animal species and categories, such as poultry, cattle and pigs. For rabbits, some general values are provided in the same CIGR document and other authors provide experimental results in which carbon dioxide emissions from rabbits were measured (e.g. Kiwull-Schöne *et al.*, 2001; 2005; Estellés *et al.*, 2009; 2010).

It is know, than the metabolism of the animals is not constant during the day, thus the production of carbon dioxide cannot be considered constant during the day for most animal species CIGR (2002). A direct relationship between the amount of CO_2 released by the animals and their daily activity index has been described in the literature (Blanes and Pedersen, 2005; Pedersen *et al.*, 1998). The CIGR (2002) proposes sinusoidal curves to model this dairy variation on animal activity and CO_2 production for most livestock species but for rabbits. Estellés *et al* (2010) proposed a cosine model to predict daily variations in CO_2 production from fattening rabbits. In addition, it's also known that the metabolic rate, and consequently the respiration rate, of the animals can be influenced by environmental conditions, mainly the air temperature. In this sense, the CIGR (2002) provides an equation in which the effect of temperature over the total heat production of the animal can be predicted for different temperatures.

Regarding to the amount of carbon dioxide that is emitted by the manure in the building, a relationship of 4% over the CO_2 production from animals can be used according to van Ouwerkerk and Pedersen (1994)

Therefore, if considering the effect of manure in carbon dioxide emission, as well as both factors affecting carbon dioxide release rates from the animals, Equation 1 can be expanded to Equation 2:

$$V'_{CO_2} = \left(CO_{2rel\_anim}\ M\right)\ T\ D\ \left(CO_{2outlet} - CO_{2inlet}\right)^{-1}\ N^{-1} \qquad (2)$$

Where:

V'_{CO2}: Ventilation flux per animal estimated through CO_2 balance corrected for temperature and daily variation (m^3 h^{-1} $animal^{-1}$)

CO_{2rel_anim}: Carbon dioxide produced by the animals (mg h^{-1})

M: Fraction of CO_2 released from manure (dimensionless)

T: Correction factor for temperature (dimensionless)

D: Correction factor for daily variation (dimensionless)

Carbon dioxide production from fattening rabbits can be determined according to their live weight following the regression equation (Equation 3) found in an experimental work by Estellés *et al* (2010):

$$CO_{2animal} = 2,66\ LW^{0.85} \quad (3)$$

Where:

$CO_{2animal}$: Carbon dioxide production (mg h^{-1})

LW: Live weight of the animal (kg)

The effect of temperature over the production of carbon dioxide by animals can be modeled following the CIGR correction factor for total heat production (Equation 4)

$$T = 1 + 4\ 10^{-5}\ (20 - t)^3 \quad (4)$$

Where:

t: Temperature (ºC)

Regarding to the daily variation, the circadian rhythm for CO_2 production described by Estellés *et al* (2010) can be expressed by Equation 5 related to the hour of the day (0-23 hours)

$$D = 1 - 0.16\ \cos\left(h\ 2\ \pi\ 24^{-1} - 14.87\ 2\ \pi\ 24^{-1}\right) \quad (5)$$

Where:

h: Hour of the day

The accuracy of carbon dioxide balance methods when determining ventilation rates has been successfully tested for most of farm species, such as poultry (Li *et al.*, 2005; Xin *et al.*, 2009) and pigs (Blanes and Pedersen, 2005), but not for rabbits. In this sense Xin *et al.* (2009) found better results when increasing the measuring integration time (averaging) from 10 to 120 min.

Therefore, the aim of this work was to test the accuracy of carbon dioxide balances methods to estimate ventilation rates in fattening rabbit houses, by comparing ventilation rates measured and calculated through the CO_2 balance in two fattening rabbit houses at different measuring integration times.

MATERIAL AND METHODS

Experimental farms and animals

Two rabbit farms located in the Spanish Mediterranean area were monitored for gas emissions. Both farms followed the same management system for the animals and differed in size (1,500 places in Farm 1 and 3,600 in Farm 2). Measurements in Farm 1 were conducted in autumn while measurements in Farm 2 were made in summer. The number of days measured in each farm are summarize in Table 1.

Table 1. Temporal layout of gas measurements in farms.

Farm	Measurement days	Season
1	29	Autumn
2	17	Summer

As the farms followed the standard management system for rabbits breeding in Spain, animals from different ages (covering the whole fattening period) were housed in the buildings during the experiments. It can be considered a homogeneous distribution of animals according to their age and weight. Therefore, considering that the normal values for the initial and final weights in Spanish conditions are 0.5 and 2 kg respectively, an average weight of 1.25 kg was considered. Animals were feed *ad libitum* during the measurement period.

Gas concentrations and environmental conditions measurement

Carbon dioxide concentrations were measured using a photoacoustic monitor (Innova-1412, Air Tech Instruments, Denmark). Air samples were conducted through Teflon tubes to a multiplexing system which allowed consecutive measurements at eight points every two hours. At least two internal sampling points were registered in each building, which were located at the air exhaust. In all cases, two external sampling points were used to determine background concentrations Temperature and relative humidity sensors (HOBO H8-004-002, Onset Computer Corp.) were also located inside and outside the buildings. Figure 1 shows the general scheme of both farms as well as the distribution of fans and sampling points.

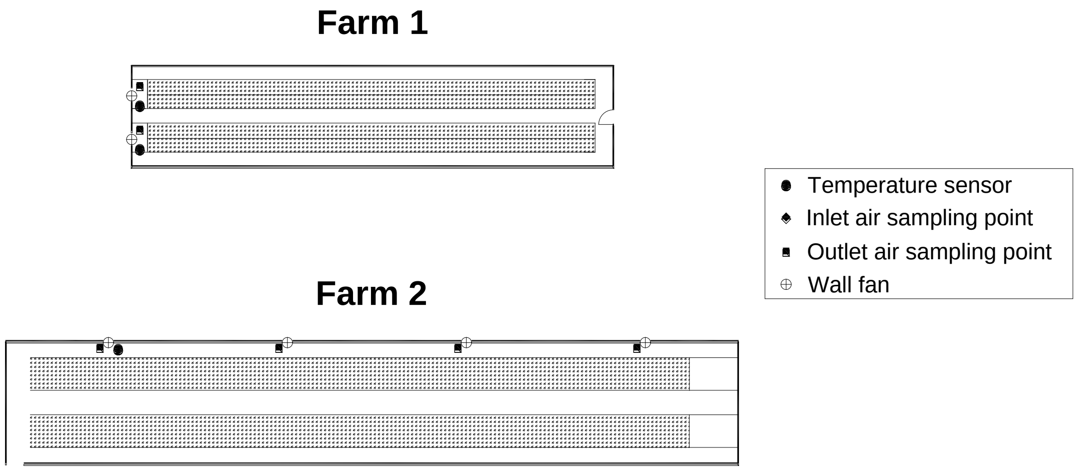

Figure 1. Constructive scheme of both farms, including the location of fans and sampling points for gases and temperatures.

Ventilation rate measurement

Both farms were equipped with constant flow wall fans. Ventilation rates were calculated considering the operation time of each fan and the corresponding fan performance at the nominal pressure drop in the farm. The percentage of time each fan was operational was registered by means of an electrical circuit connected to the auxiliary contacts of the fan relays, similar to the systems described by Muhlbauer *et al*. (2006). Fan status was recorded every minute by means of a voltage data logger (HOBO H08-004-02, Onset Computer Corp., USA). Each fan was calibrated for airflow before and after each experiment, multiplying the free flow area by the average air speed in the fan. Air velocity was measured at 24 points of the cross section of the fan by means of a hot wire anemometer (Testo® 425; with measurement range 0 to 20 m•s-1) following the general recommended procedure (ASHRAE, 2001).

Data analysis

The accuracy of the carbon dioxide balance for the estimation of ventilation flux was tested using a regression model. The REG procedure of SAS (2001) was used. The model is described in Equation 6:

$$V = \alpha \, V'_{CO_2} + \varepsilon \qquad (6)$$

Where:

V: Measured ventilation rate ($m^3\ h^{-1}\ animal^{-1}$)

α: Regression parameter (dimensionless)

ε: Model error (dimensionless)

To analyze the effect of measurement integration time (MIT), average ventilation rates were determined for three different periods: 2h, 12h and 24h.

RESULTS AND DISCUSSION

Direct ventilation rate measured

Results from direct ventilation rates measured in both farms during the experiments, as well as outside temperatures for the same periods are presented in Figure 2.

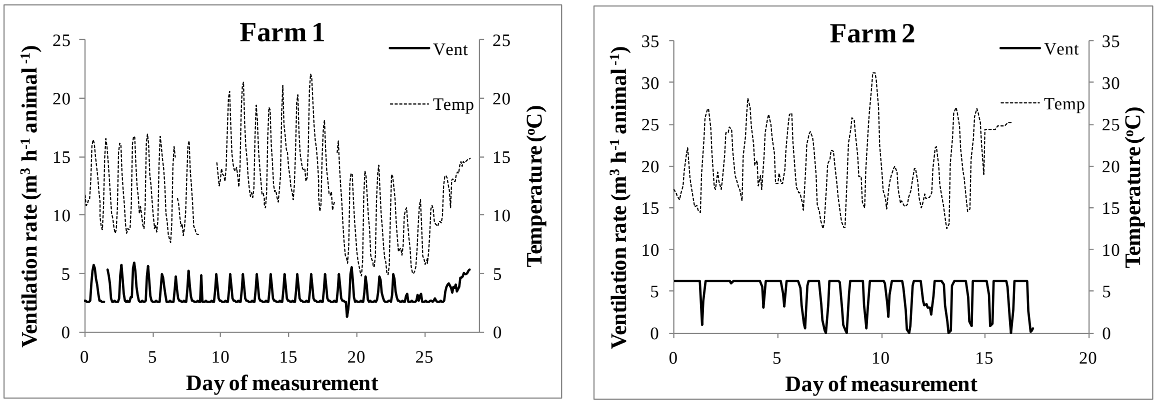

Figure 2. Ventilation rates and outside temperatures registered in both farms.

As expected, a positive correlation between outside temperature and ventilation rates was observed. Ventilation rates per animal were higher in Farm 2 than in Farm 1, due to the higher temperatures observed in the outside. The performance of ventilation systems was different between farms. In Farm 1 a minimum ventilation rate (around 3 m^3 h^{-1} per animal) was fixed by the farmer in order to renew the air inside the building. By the contrary, in Farm 2 a maximum ventilation rate can be observed (around 6 m^3 h^{-1} per animal), due to the maximum capacity of the ventilation system of the farm.

Carbon dioxide concentrations

CO_2 concentrations measured in both farms are shown in Figure 3.

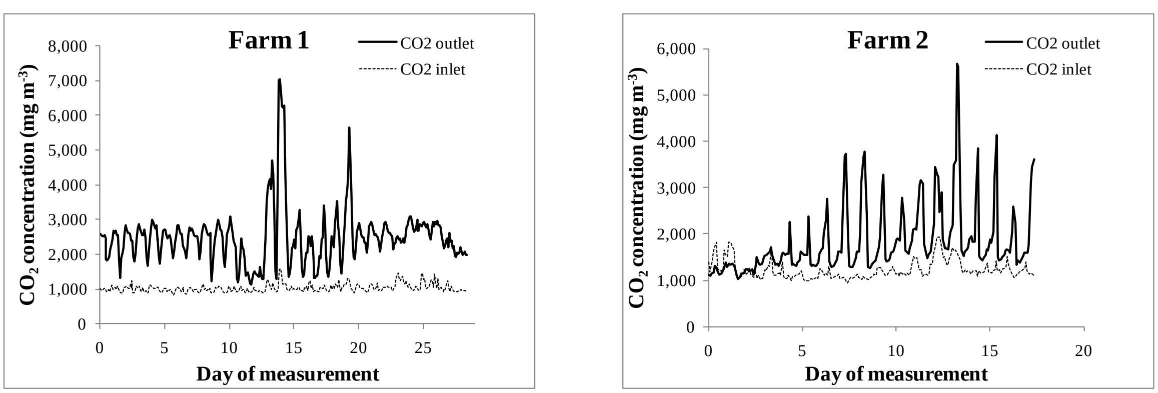

Figure 3. Inlet and outlet CO_2 concentrations registered in both farms.

Average CO_2 concentrations in the inlet air were 1,028±119 mg m^{-3} and 1,227±204 mg m^{-3} for farms 1 and 2 respectively. Those values are higher than normal values for clean air. This could be explained by the location of the buildings, near to other animal houses. The differences between outlet and inlet concentrations ranged from 235 to 5,448 mg m^{-3} in Farm 1 (average 1,460±235) and from -550 to 4,105 mg m^{-3} in Farm 2 (average 598±741). Those values are generally over the minimum difference of 270 mg m^{-3} proposed by Pedersen *et al*. (1998) for the calculation of ventilation rates through CO_2 balances.

Calculated ventilation rates

The relationship between measured and calculated ventilation rates, using the carbon dioxide balance in both farms, for different measuring integration times (MIT) is presented in Figure 4.

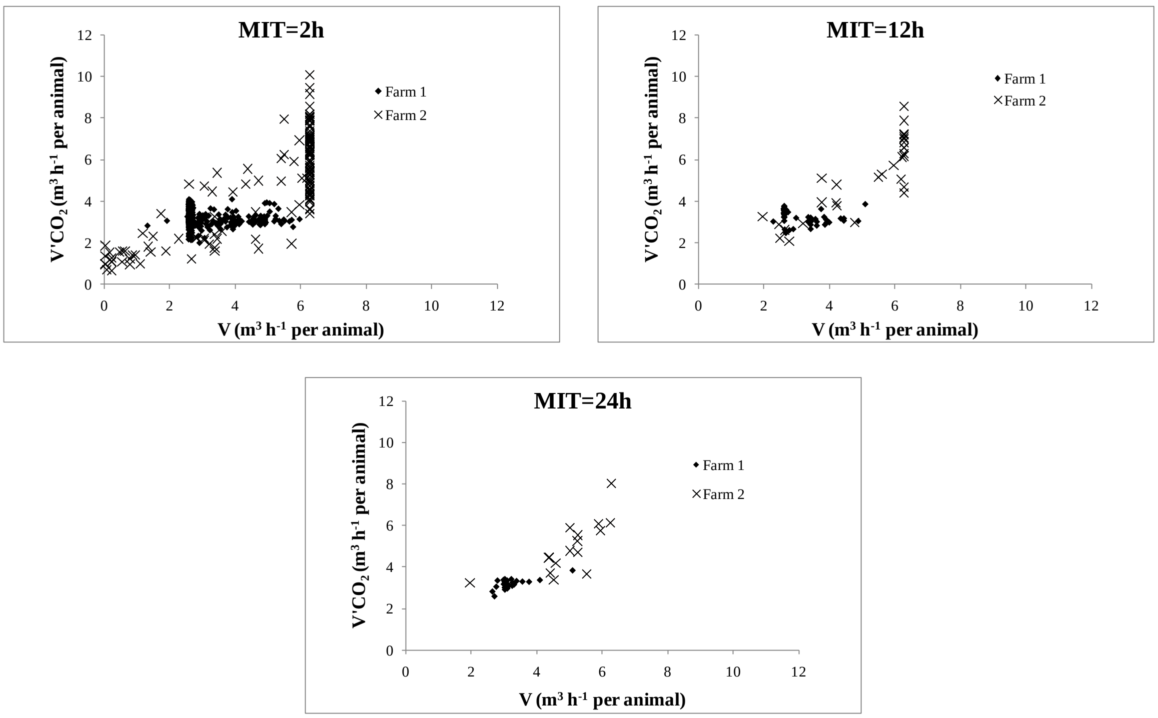

Figure 4. Measured and estimated ventilation fluxes for Farms 1 and 2 at different MIT (2 h, 12 h and 24 h)

The average absolute value of the errors committed using carbon dioxide balances to determine the ventilation rate using measured values expressed as the percentage of deviation over the measured ventilation rate were, higher in Farm 1 for MIT=2h and 12h (25.97%±14.63 and 22.71%±11.46 respectively) than in Farm 2 (27.04%±27.10 and 15.51%±14.63 respectively). By the contrary, when the integration time increased to 24 hours, the error committed using Farm 1 values (7.58%±6.15) were lower than those obtained when considering the data from Farm 2 (14.31%±17.33).

These deviations are higher than the values obtained by Xin *et al*. (2009) for broilers (from 6.9% to 7.5%), van Ouwerkerk and Pedersen (1994) for cattle (5.2%) and Blanes and Pedersen (2005) for pigs (8%).

The results of the regression lines calculated following Equation 6 are shown in Table 2.

Table 2. Linear regression between measured and estimated ventilation flow for different MIT

Farm	MIT (h)	R^2	α	SE	P-value	Intercept	SE	P-value
1	2	0.01	-0.17	0.08	<0.05	3.94	0.27	<0.05
	12	0.03	N.S.		0.10	4.65	0.90	<0.05
	24	0.55	1.89	0.32	<0.05	-2.57	0.97	<0.05
2	2	0.62	0.70	0.04	<0.05	N.S.		0.62
	12	0.71	0.71	0.08	<0.05	N.S.		0.71
	24	0.38	0.52	0.16	<0.05	N.S.		0.38

Attending to the results of the regression lines, the prediction models obtained for Farm 1 are not successful, despite an increase of R^2 can be observed when using 24-hours average values for the regression. Regression values obtained using data from Farm 2 resulted in higher R^2 values. In this sense, it can be observed as the best goodness of fit is obtained for MIT=12h and MIT=2h. Attending to the values obtained for the slope (α) of the regression lines, it can be noticed that the carbon dioxide balances overestimate the ventilation rate by 30%, 29% and 48% for MIT=2h, 12h, and 24h respectively. Those values differ from previous studies (Blanes and Pedersen, 2005; Li *et al.*, 2004; Pedersen *et al.*, 1998; Xin *et al.*, 2009) in which ventilation rates calculated using carbon dioxide balances lead to an underestimation of airflow rates.

CONCLUSIONS

The use of CO_2 balances for the determination of ventilation rates in fattening rabbit buildings leads to higher errors than those reported for other species. Errors obtained in this work, ranged from 7% to 27% in relation to direct ventilation rate measurements.

In general, better results for the regression lines among measured and modeled ventilation rates were obtained when increasing the measurement integration time from 2h to 12h. When using 24-hours average values for the balances, the improvement could be observed in Farm 1.

Further research is needed in order to determine carbon dioxide release rates from fattening rabbits and their manure.

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