THE INFLUENCE OF ANIMAL ACTIVITY AND LITTER ON CARBON DIOXIDE BALANCES TO DETERMINE VENTILATION FLOW IN BROILER PRODUCTION

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ABSTRACT Carbon dioxide (CO_2) balances are useful tools to determine ventilation flows in animal buildings. This method needs an accurate estimation of the average CO_2 production by animals to determine daily average ventilation flows. To estimate the daily variation in ventilation flow, the daily variation in the production of this gas is also necessary, which mainly depends on animal activity. The main objectives of this work were to quantify the amount of CO_2 produced by the litter, to determine the CO_2 produced by broilers as a function of animal weight, and to analyse the influence of animal activity on this emission. Gas concentrations and ventilation flows were simultaneously measured in one experimental and two commercial growing cycles. In the experimental assay, animal activity was determined every 15 minutes by observation of animal behaviour and an activity index was obtained. At the end of the experimental cycle, litter accounted for 20% of total CO_2 production, and the animals produced 3.71 L hour-1 kg-0.75. In the commercial farm, CO_2 production was the same in the two cycles (2.60 L hour-1 kg-0.75). These values are higher than those reported in previous studies, probably because of differences in daily weight gain. Carbon dioxide produced by animals was influenced by animal activity, and using this parameter the CO_2 balance was improved. However, CO_2 and animal activity followed different daily patterns. Therefore, a correction for animal activity is necessary to determine daily variations in ventilation flows for broilers, but particular care should be taken if these corrections are based on observed animal activity.

Keywords: Broiler, Carbon dioxide balance, Animal activity, Gas emissions.

INTRODUCTION Measuring gas emissions from animal buildings requires the simultaneous measurement of gas concentrations and ventilation flows. In naturally ventilated buildings, and also in buildings with a large number of fans, indirect methods to measure ventilation flows may be necessary. Among indirect methods, heat, moisture

and carbon dioxide (CO_2) balances have been used (Pedersen et al., 1998). To develop carbon dioxide balances, CO_2 production from animals and also from their litter must be known.

Carbon dioxide production depends on animal weight and is strongly affected by variations in animal activity, because this gas is produced mainly in the metabolic process of the animals. The basis of the carbon dioxide balance was proposed by Feddes et al. (1984), who estimated air exchange in cattle and pig and broiler production. Van Ouwerkerk and Pedersen (1994) estimated the airflow rate in pigs and cattle with a 15% precision, according to the metabolic reactions in the animals. They quantified the carbon dioxide production as a function of the heat production of the animals. They proposed a carbon dioxide production between 0.17 and 0.20 $L \cdot h^{-1} \cdot W^{-1}$ and considered that 4% of all CO_2 production was produced by manure. This methodology has been further developed for other species (CIGR, 2002; Pedersen et al., 1998), taking into account temperature changes, animal activity and a carbon dioxide production rate of 0.185 $L \cdot h^{-1} \cdot W^{-1}$. Better correlations between measured and modelled ventilation flow were obtained in pig production when animal activity was expressly measured (Blanes and Pedersen, 2005).

The CO_2 balance method proposed by the International Commission of Agricultural Engineering (CIGR, 2002) consists of three steps. Firstly, the heat production of the animals must be calculated. Secondly, the influence of ambient temperature and animal activity is considered to obtain a corrected heat production. And finally, the ventilation flow is calculated according to measured CO_2 concentrations and the average CO_2 production rate by the animals (F_{CO_2}). Thus, ventilation flow (VCO_2) expressed in cubic meters per animal and hour on a 24-hour basis can be calculated by means of Equation 1. In this equation, CO_2 concentrations are expressed in parts per million, and ϕ^*_{tot} is the total heat production, which in turn depends on ambient temperature and animal live weight.

$$V_{CO_2} = \frac{F_{CO_2} \cdot \phi^*_{tot}}{(CO_{2\,outlet} - CO_{2\,inlet}) \cdot 10^{-6}} \tag{1}$$

The CO_2 production varies during the day due to changes in animal activity. For that reason, when the balance is performed on an hourly basis, it must be adjusted for animal activity. Although some models have been proposed to adjust daily variation of activity in pigs (Blanes and Pedersen, 2005), no model has been proposed for broilers given the high dependence of the lighting programme on animal activity (Calvet et al., 2009).

Three main problems arise when applying CO_2 balances in broiler production. The first one is related to the calculation of total heat produced by each animal, since the metabolic activity of animals may be affected by the evolution of animal genetics (e.g. improved weight gain rates in modern strains). The second one refers to the relation between heat production and carbon dioxide production. Finally, the influence of animal activity on carbon dioxide production in broiler production is not fully understood.

The main objective of this work was to evaluate effect of certain parameters involved in the development of carbon dioxide balances to determine ventilation flows in broiler production. Particular objectives were: firstly, to quantify the amount of CO_2 produced by

the litter; secondly, to determine the CO_2 produced by broilers as a function of animal weight; and finally, to analyse the influence of animal activity on this emission.

MATERIALS AND METHODS Two experiments were conducted to evaluate the carbon dioxide balance method. In Experiment 1, an experimental farm was used to determine the influence of animal activity and litter on carbon dioxide production. In Experiment 2, the carbon dioxide balance was evaluated in a commercial farm.

Experiment 1 The experimental broiler facility was located in the Division of Process Engineering (Georg-August University of Goettingen, Germany). A total of 158 one-day-old Ross broilers were distributed into twelve 2 m^2 pens in a 6x8 m room and reared until 35 days of age (Figure 1). Each pen had one manual feeder and two nipple drinkers and wood shavings were used as bedding material. Temperature, ventilation rate and lighting were adjusted to animal requirements. The light regime consisted of two dark and two light periods during the day: during the first 10 days of the cycle, the dark periods were from 23:00 to 05:00 and from 11:30 to 15:30, whereas during the rest of the experiment dark periods were from 21:00 to 05:00 and from 11:30 to 15:30. Animal weight and feed consumption were determined weekly.

The room was ventilated by a three-level constant ventilation system: level 1 during days 1 to 8, level 2 during days 9 to 28 and level 3 from day 29 to the end of the cycle. The ventilation rate of each level was measured by means of a fan-wheel anemometer (MiniAir6/S6Mik20, Schlitknecht, Switzerland), resulting in 347, 387 and 414 $m^3 \cdot h^{-1}$ for levels 1, 2 and 3, respectively. Air temperature and relative humidity at air exhaust and at animal height were measured using temperature and humidity sensors (Hydroclip, Rotronics, Switzerland) and continuously recorded in a data logger (Mikromec-multisens, Technetics, Germany). Carbon dioxide concentration was determined every 30 minutes using a FTIR analyzer (ThermoNicolet 470 ED, USA). Animal activity was measured by direct observation in video tapes every 15 minutes as explained in Calvet et al. (2009), and an activity index (Ai) was defined as the proportion of active birds.
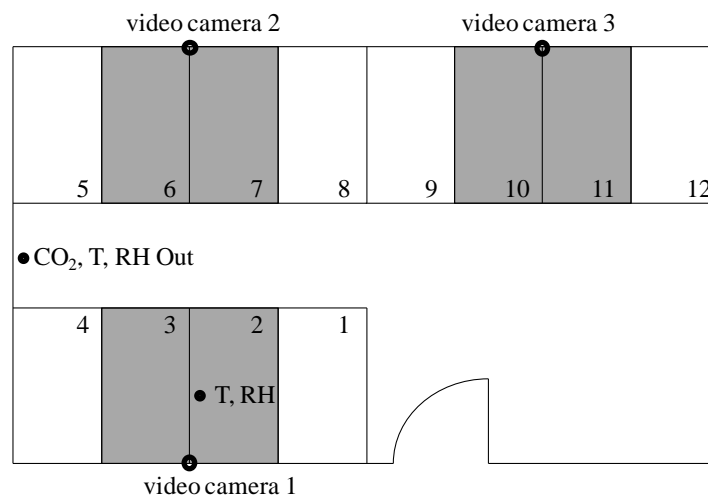

Figure 1. Experiment design, including the distribution of the pens, the monitoring of animal activity (dashed areas), and the measurement point for carbon dioxide (CO_2), temperature (T) and relative humidity (RH) in the experimental farm.

Experiment 2 In the second experiment, carbon dioxide production was quantified in two growing cycles in a commercial, mechanically-ventilated broiler farm located in Villarreal (Castellón, Spain). One cycle corresponded to summer conditions and the other to winter, and the evaluated period was the same as in the experimental farm (days 1 to 35). The building was equipped with 16 constant flow fans. This farm is representative of the commercial farms in this region. Rice hulls (approximately 8-10 cm deep, 4 kg·m^{-2}) were used as bedding material, and the litter was removed at the end of the cycle. The summer experiment started with 10,000 male and 10,100 female chicks on 20th July 2006 and the winter experiment started on 15th December 2006 with 12,000 male and 12,000 female broiler chicks. Animal weight and feed consumption was determined weekly.

To determine ventilation flow, the operation time of each fan was recorded hourly during the two cycles. Each fan was also calibrated at the beginning and at the end of the experiment, at four different pressure drops (0, 15, 30 and 45 Pa). Air speed was measured using a hot-wire anemometer (Testo 425, range 0-20m·s^{-1}, precision 5% of reading). Pressure drop was measured and recorded every 5 minutes using the 0-2.5V analog output of a differential pressure transducer (Setra model 267, range 0-100 Pa, Mass., USA).

Carbon dioxide concentration was measured using a photo acoustic gas monitor (INNOVA 1412, Denmark) equipped with a gas multiplexer that allowed sequential measurement in 8 different points in a 2-hour sequence (15 minutes for each measurement). As shown in Figure 2, four sampling points were placed next to the extraction fans to determine exhaust gas concentrations, two at the air inlet openings for the characterization of outside air, and the other two measurement points were placed in the middle of the building. Temperature and relative humidity were continuously measured both indoors and outdoors, using four data loggers and a weather station (H8-004-002 and HOBO Weather Station, Onset Computer Corp., Pocasset, Mass.).
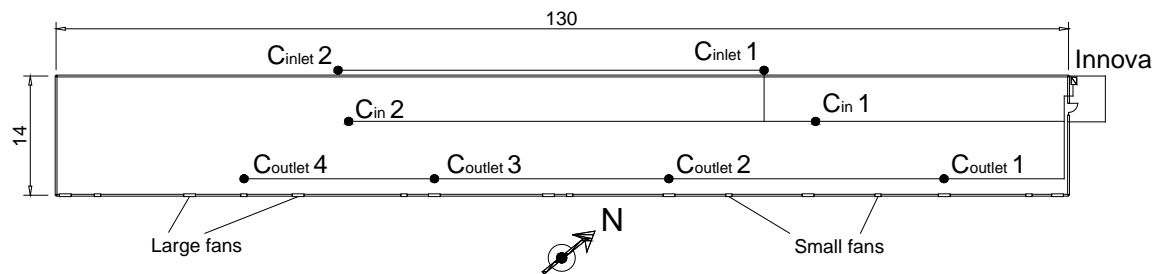

Figure 2. Distribution of the farm: location of the gas concentration sampling points and environmental monitoring systems in the commercial farm.

Data analysis The carbon dioxide balance method for estimating ventilation flows was evaluated by combining the equations from CIGR (2002). The obtained the following expression was used, relating the estimated ventilation flow (V_{CO2}, m^3·animal^{-1}·h^{-1}) with input variables.

$$V_{CO_2} = \frac{F_E \cdot LW^{0.75} \cdot F_T \cdot F_{CO_2} \cdot F_A}{\left(CO_{2\,outlet} - CO_{2\,inlet}\right) \cdot \left(1 - F_{litter}\right) \cdot 10^{-6}} \tag{2}$$

where F_E is the heat production factor (watts per kilogram of metabolic weight); LW is the live weight expressed in kilograms; F_T is the dimensionless correction factor for temperature, F_{CO2} is the carbon dioxide production expressed in litres per watt; F_A is a dimensionless correction for animal activity; CO_2 concentrations are expressed in parts per million and F_{litter} accounts for the proportion of carbon dioxide produced by litter. The last variable was estimated considering the average proportion of CO_2 production during the first 24 hours after slaughter, in relation to the last four days of the rearing period, and assuming a constant value for F_{litter} (Xin et al., 2009).

Ideally, the model gives similar values for measured and estimated ventilation flows. Therefore, we can compare the different measured values of ventilation flow with the measured parameters. In Equation 3 all directly measured values were grouped in the left part of the following expression.

$$V_{measured} \cdot \left(CO_{2\,outlet} - CO_{2\,inlet}\right) \cdot \frac{\left(1 - F_{litter}\right)}{F_T} \cdot 10^{-6} = F_A \cdot F_E \cdot F_{CO_2} \cdot LW^{0.75} \tag{3}$$

The left part of Equation 3 refers the measured carbon dioxide production by animals (E_{CO2}) expressed in litres per animal and hour. If the unknown variables in the right part of Equation 3 are grouped, the following regression model relates the emission of carbon dioxide to animal live weight:

$$E_{CO_2 i} = \alpha \cdot LW_i^{0.75} + \varepsilon_i \tag{4}$$

Where α is the regression parameter and ε_i is the model error. This model was evaluated with average daily values using the PROC REG of SAS System® (SAS, 2001). Using daily averages, the correction for animal activity F_A is, by definition, not necessary.

To assess the influence of animal activity on carbon dioxide production per kilogram of metabolic weight ($E_{CO2\,MW}$), two models were tested, using average values every 30 minutes from the experimental assay. The first model (Equation 5) is an analysis of variance considering the effect of light status (Light), whereas Equation 6 is a linear regression model considering the influence of animal activity (Ai), where β_1 and β_2 are the regression parameters:

$$E_{CO_2 MW\ i} = \mu + Light_i + \varepsilon_i \tag{5}$$

$$E_{CO_2 MW\ i} = \beta_1 + \beta_2 \cdot Ai_i + \varepsilon_i \tag{6}$$

RESULTS

Productive results In the Experiment 1, the average body weight gain from day 1 to 35 was 62.1 g·day^{-1}, whereas in the commercial farm the average body weight gain in the same period was 45.3 and 50.0, respectively. Other productive results are shown in Table 1.

Table 1. Productive results in the studied cycles

Farm	LW (kg) Day 35	LW (kg) Day 48	Global feed conversion ratio	Mortality at day 35 (%)
Experiment 1	2.17	-	1.53	5.06
Experiment 2 – Summer	1.59	2.43	1.83	5.14
Experiment 2 - Winter	1.75	2.69	1.82	3.28

Emissions from litter The relationship between the mean carbon dioxide production before and after slaughter was obtained in the experimental farm from the carbon dioxide production curve (Figure 3). Before slaughter (days 30 to 33), average carbon dioxide production was 6.81 litres per animal and hour, originated both from animals and litter; during the first 24 hours after slaughter, average carbon dioxide production was 1.36 litres per animal and hour. Assuming that there is no change in carbon dioxide production from litter between these two estimations, 20% of the total carbon dioxide was produced by the litter ($F_{litter} = 0.2$).
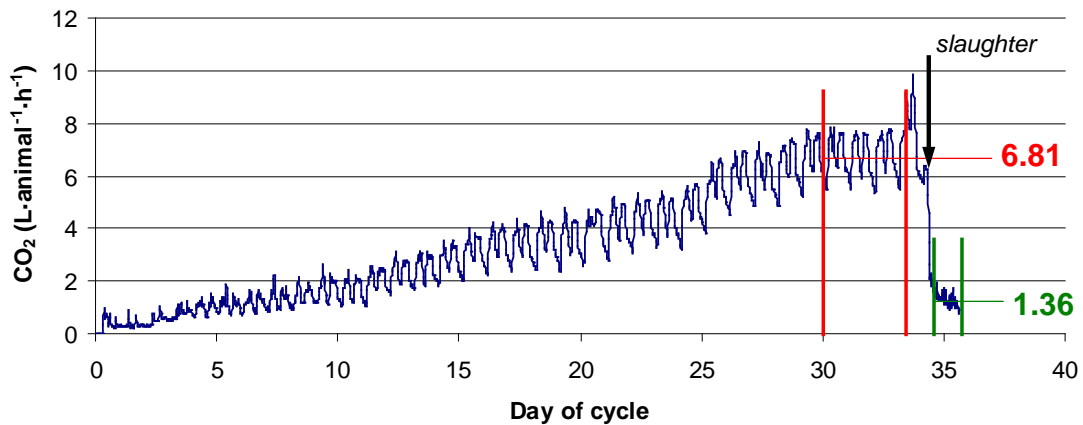

Figure 3. Evolution of the carbon dioxide production and estimation of average productions before and after slaughter

Carbon dioxide production rate Daily average carbon dioxide productions are represented against metabolic weight of the animals in Figure 4. In both experiments, a linear tendency was observed and linear regression parameters according to Equation 4 are shown in Table 2. In the commercial farm, no differences ($p < 0.01$) were found between the summer and winter cycles. However, between commercial and experimental studies a statistical difference was found in the carbon dioxide production rate.
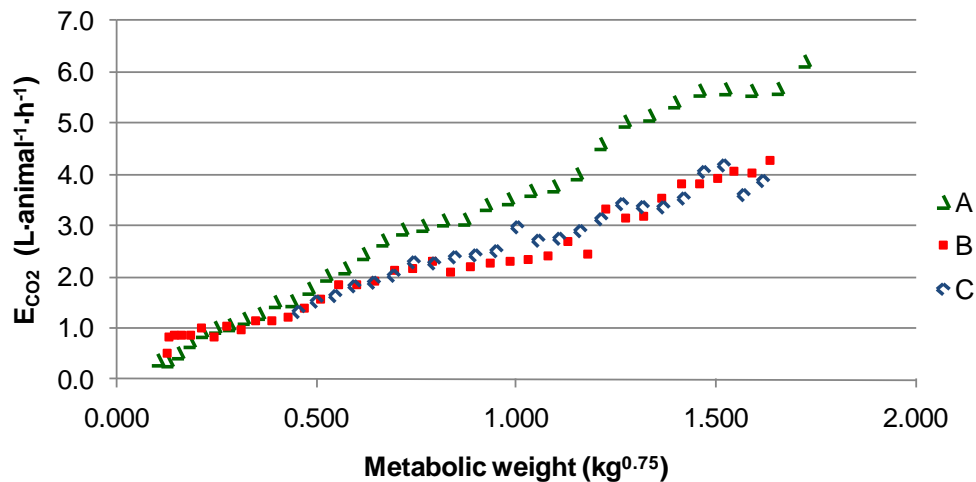
Figure 4. Relation between daily average CO_2 production and animal weight in the experimental farm (A) and in the commercial farm in summer (B) and in winter (C)

Table 2. Linear regression of carbon dioxide production (L·animal^{-1}·hour^{-1}) as a function of metabolic weight (kg$^{0.75}$) in the experimental and commercial farms

Farm	R^2	α	SE	P-value
Experiment 1	0.98	3.71	0.03	<0.01
Experiment 2 – Summer	0.97	2.59	0.05	<0.01
Experiment 2 - Winter	0.96	2.62	0.04	<0.01

Effect of animal activity The light status affected significantly (p<0.01) the carbon dioxide production with an average emission value of 3.03 ± 0.02 and 3.85 ± 0.02 L·animal^{-1}·kg$^{-0.75}$ during the dark and light periods, respectively. Finally, CO_2 emission per kilogram of metabolic weight was also significantly (p<0.01) affected by animal activity (Equation 7).

$$E_{CO_2 MW} = 2.94 \ (\pm 0.02) + 1.56 \ (\pm 0.02) \cdot Ai \qquad \left(R^2 = 0.40\right) \qquad (7)$$

The correction of the balance for animal activity using the activity index defined previously improved the precision of average hourly ventilation rates. When animal activity was considered, the standard deviation of the residuals (estimated against measured ventilation flows) decreased from 32% to 21%. However, the variation in carbon dioxide production in the time was not completely coherent with the variation of animal activity, since discrepancies were found in the change between dark and light periods. Carbon dioxide production and the activity index during the last two days of the rearing period are shown in Figure 5. A change in the light status did not involve an immediate change in CO_2 production by animals. The change in CO_2 concentration was produced smoothly, particularly when changing from light to darkness.
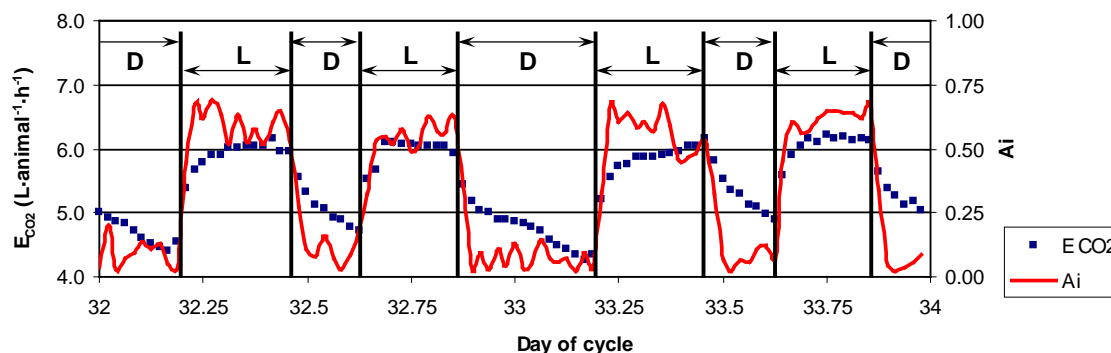
Figure 5. Evolution of the carbon dioxide (ECO_2) production and the animal activity index (Ai) during the days 32 and 33. Light status is indicated (L=Light; D=Dark)

DISCUSSION

Carbon dioxide production rate In this study, carbon dioxide production was positively related with metabolic weight. Table 3 compares the results of the present work with previous studies. The estimation of α includes the parameters F_E and F_{CO2}. According to CIGR (2002), a value of 10.62 is proposed for F_E, and 0.185 for F_{CO2}, thus α equals 1.965, which is almost half the value obtained in experiment 1. It seems that inaccuracies in the measurements are not enough to explain these differences. However, F_E may be higher than those values previously reported given the increased animal growth rates over the last decades, as reported for pigs by CIGR (2002). In the experimental study, the animals grew faster than in usual conditions, and this could have caused a greater carbon dioxide production. Considering the estimation of α (3.71) and assuming that F_{CO2} is 0.201 $L \cdot h^{-1} \cdot W^{-1}$ according to Blanes and Pedersen (2005), the F_E estimated in this study would be 18.46, which is 74% higher than the value proposed by CIGR (2002). This disagreement is still large enough to consider further studies to determine F_E more precisely. In the commercial farm, the estimation of F_E was 32% higher than the value proposed by CIGR. The emission, however, was lower than in the experimental study, probably due to differences in growth rates.

Table 3. Comparison of values of F_E and F_{CO2} between our results and other studies

Method	F_E ($W \cdot kg^{-0.75}$)	F_{CO2} ($L \cdot h^{-1}W^{-1}$)	$α = F_E \cdot F_{CO2}$
CIGR (2002)	10.62	0.185	1.96
Xin et al. (2009)	10.62	0.157	1.66
This study (experimental)	18.46 [1]	0.201 [2]	3.71
This study (commercial)	12.94 [1]	0.201 [2]	2.60

[1] Indirectly estimated

[2] Estimated according to Blanes et al. (2005)

In a similar study, Xin et al. (2009) compared measured ventilation flow and estimated flow considering a carbon dioxide balance, in two flocks of broilers. They found a good agreement between measured and estimated flow considering $F_E = 10.62$ according to CIGR (2002), and $F_{CO2} = 0.157$ based on the principle of animal calorimetry.

Differences between studies could be explained by significant differences in daily body weight gain, as presented in Figure 6. Although this graph shows estimated values according to Table 3, and there is not enough information to establish a linear relationship between daily weight gain and F_E, there is strong evidence that heat production (and thus CO_2 emission rate) may be affected by animal growth rate (CIGR, 2002).
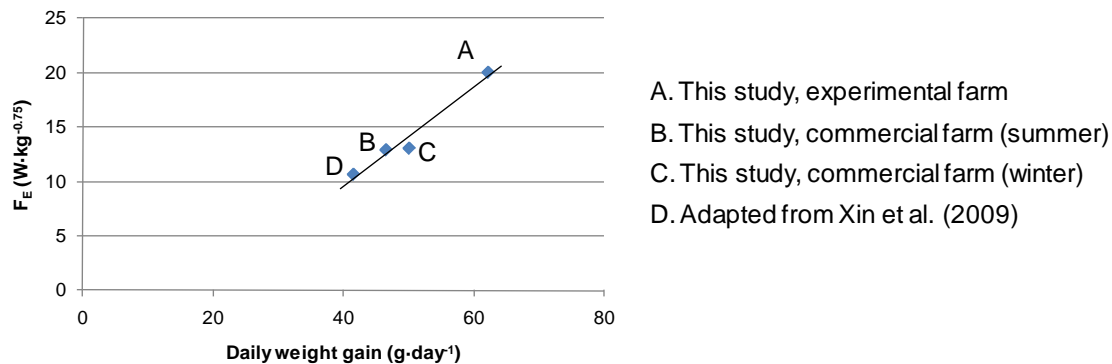

A. This study, experimental farm
B. This study, commercial farm (summer)
C. This study, commercial farm (winter)
D. Adapted from Xin et al. (2009)

Figure 6: The influence of daily weight gain on F_E proposed in different studies

The influence of animal activity Light status affected animal activity, and therefore had a clear indirect effect on CO_2 production. The effect of animal activity on CO_2 production can be interpreted as follows: The first term of Equation 6 (2.94 $L \cdot animal^{-1} \cdot kg^{-0.75}$) represents the tranquil CO_2 exhalation rate (TCER) proposed by Ni et al. (1999) for pigs. From this basal value, the activity of the animals can cause an increase of as much as 53% in the carbon dioxide production depending on the Ai. The animal activity index could only explain 40% of CO_2 variation during the day. Therefore, observed animal activity may not be a precise estimator of the variation in CO_2 production.

A possible reason for the progressive change in CO_2 emission between light and dark periods is the fact that CO_2 concentrations change according to a decay formula, and therefore cannot change drastically. However, given the ranges of gas concentrations, the ventilation rates and the volume of the building, 99% of the concentration change is produced within the first 20 minutes, and therefore, this smooth change between dark and light periods would not be detectable with a 30-minute measuring interval.

The other reason for this is that when a change in the light occurs, a change in animal activity is perceived, and thus the Ai changes. Nevertheless, the metabolic status is not reflected by the observed activity. This is particularly significant in the first hours of sleep. According to Shapiro and Flanigan (1993), there is a transition from wakefulness to sleep, characterised by active brain activity, which could explain the smooth transition in carbon dioxide production by animals. According to these authors, one of the functions of sleep is energy conservation, decreasing the metabolic rate (oxygen consumption, heart rate, body temperature and thus CO_2 production) by 5 to 25%.

CONCLUSION Average daily carbon dioxide production varied linearly with the metabolic weight of the animals from days 1 to 35 of the growing cycle. However, the application of the carbon dioxide balance resulted in a higher CO_2 emission than the obtained in previous studies. This may be probably a consequence of the different animal

growth rates. Litter accounted for 20% of total CO_2 production at the end of the growing cycle.

Animal activity, as defined in this study, could not be precisely related to carbon dioxide production because the movements of the animals cannot be directly related to their metabolic activity, particularly during the first hours of the dark periods. Therefore, particular care should be taken when applying correction factors for animal activity to estimate ventilation flow using carbon dioxide balances in broilers.

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