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A SIMPLIFIED METHOD TO ASSESS GREENHOUSE GAS AND AMMONIA EMISSION FACTORS OF FATTENING PIGS REARED ON FULLY SLATTED FLOOR.

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ABSTRACT

Measurements of greenhouse gases and ammonia emissions can be performed by measuring continuously concentrations in rooms during the whole rearing period. Nevertheless, time and cost relative to this method limit the application to a large number of facilities and is not appropriate to assess the variability of emissions in relation to housing systems, farmer practices and climate. In order to border this variability and to identify mitigation strategies, simplified methods have to be developed. To do so, during winter 2006 and summer 2007, NH_3, N_2O, CO_2, CH_4 and, H_2O emissions from fattening pigs were measured continuously during the whole rearing period. Pigs were fattened between 30 and 100 kg and kept on fully slatted floor. For validation, a comparison of measured emissions for both batches with the nitrogen and carbon mass balances deficits showed that 85 and 105 % of total nitrogen and carbon losses were explained by measured gaseous emissions. Based on the emissions kinetics obtained during continuous measurements, emissions were calculated using the concentrations ratios method. This method is based on carbon losses deduced from carbon mass balance combined with mean gas concentrations ratios obtained with spot measurements during the rearing period. Results showed that intermittent gas concentrations measurements performed during 4 hours in the afternoon on days 24, 60, 80 allow the assessment of emissions factors with an error lower than 20%.

KEYWORDS. Greenhouse gas, ammonia, emission factors, fattening pig, fully slatted floor.

INTRODUCTION

In France, the agriculture sector is responsible for 19% of greenhouse gas emissions, with 46% of that contributed by animal breeding (CITEPA, 2008). For ammonia, agricultural activities contribute up to 95%, with 72% due to animal production (CITEPA, 2008). Greenhouse gas (GHG) and ammonia (NH_3) emissions contribute to global warming, acidification phenomena and eutrophication, and need to be controlled and reduced. However, no emission factors representative of French agricultural practices have been validated. Current methods implemented to define emission factors are based on continuous measurements. However, even if these continuous measurement methods are accurate, their application to a large number of facilities represents a major drawback in terms of time and cost. Therefore, it's necessary to simplify the current methods in order to multiply acquired data and to establish emission factors under French livestock conditions.The objective was to develop a simplified method based on the analysis of continuous measurements in order to identify the duration and frequency of the best times for spot measurements.

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MATERIAL AND METHODS

Housing and animals

The study was carried out in the IFIP experimental farm at Romillé (Brittany – France) and covered two fattening periods of 60 pigs (PPxLW)x(LWxLd) reared from 30 to 110 kg during winter 2006 and summer 2007. A third batch (winter 2008) was fattened and used for the validation of the simplified method. The total surface area per pig was 0.7 m^2. Pigs were reared on fully concrete slatted floor with slurry storage underneath during the whole period of fattening (pit depth = 0.8 m). Slurry samples were taken at the feed change and just before departure for slaughterhouse and analyzed with standard methods to assess the density, pH, dry matter, total carbon and nitrogen, ammoniacal nitrogen, phosphorus and potassium contents. The total volume of slurry produced in the pit was also measured. Pigs were weighted at the beginning, at 65 kg for the feed change and just before slaughtering.

In the building, fresh air entered via a ceiling of perforated sheeting and air exhaust was under-floor extraction with chimney. Pigs were fed ad libitum with growing feed up to 65 kg and then with finishing feed until slaughtering. Both feeds were formulated on the same energy base (9.3 MJ/kg of Net Energy (NE)). The dietary crude protein levels were 16.5 and 15% respectively for the growing and the finishing feeds with a digestible lysine level respectively of 0.9 and 0.8 g/MJ of NE._Feed consumption was recorded per pen between two weights. Water consumption was recorded weekly.

Development of the simplified method

The simplified method was based on the concentration ratios method (CRM – Paillat et al., 2005) adapted to pig housing. The following equations (equations 1 to 5) have been used:

$$C\ losses = E_{CO2\_C} + E_{CH4\_C} \quad (1)$$

with E_{CO2_C} and E_{CH4_C} are C emissions in CO_2 and CH_4 forms, respectively.

Based on these equations, we expressed the emissions for each gas produced in the building:

$$E_{CO2\_C} = C\ losses/[1 + (Gradient_{CH4\_C}/Gradient_{CO2\_C})_{mean}] \quad (2)$$
$$E_{CH4\_C} = E_{CO2\_C} * (Gradient_{CH4\_C}/Gradient_{CO2\_C})_{mean} \quad (3)$$
$$E_{NH3\_N} = E_{CO2\_C} * (Gradient_{NH3\_N}/Gradient_{CO2\_C})_{mean} \quad (4)$$
$$E_{N2O\_N} = E_{CO2\_C} * (Gradient_{N2O\_N}/Gradient_{CO2\_C})_{mean} \quad (5)$$

where E_{NH3_N} and E_{N2O_N} are N emissions in NH_3 and N_2O forms, respectively. Concentrations were obtained by spot measurements achieved in pig housing. The adaptation of the CRM to pig housing was organized in four successive steps:

1- Monitoring of the gas emissions kinetics and emission factors validated by the mass balance method.

2- Comparison of carbon losses calculated with farm data vs reference data.

3- Identification of the good periods, duration and frequency for spot gas concentration measurements.

4- Validation of the simplified method with an additional batch

Step 1: Gaseous emission measurements and validation

Climatic conditions

Indoor and outdoor temperature and humidity were continuously recorded during the whole period of fattening with temperature and humidity sensor (type TESTO 177H1). The ventilation rate was also continuously monitored (every 15 minutes) by measuring the rotation speed of a full-size free-running impeller unit, coupled with the exhaust fan of the rearing rooms (FANCOM).

Outside the building, the weather conditions were monitored with a weather station from Campbell Scientific including a wind monitor 05103, a pyranometer SP1110, a temperature and humidity probe MP100A, a rain gauge ARG100 and a barometric pressure sensor RPT410F connected to a datalogger (CR10X Campbell Scientific).

Gaseous concentration measurements

Concentrations were measured by photoaccoustic infrared absorption spectrometry using a gas analyzer (INNOVA 1412) coupled to a sampler dosimeter (INNOVA 1303) with six sampling lines located as follows: three in the rearing room, one in the perforated ceiling, two outside the livestock building. The air samples were taken successively and automatically every 2 minutes and analyzed during 15 minutes for each sampling location. The analyzed gases were ammonia (NH_3), nitrous oxide (N_2O), carbon dioxide (CO_2), methane (CH_4) and water vapor (H_2O). The sampling periods per batch are presented in Table 1.

Table 1. Sampling periods per batch

Batch	Fattening start	Period 1	Period 2	Fattening end	Measurement Duration (days)
Winter 2006	10-12-2006	11-03-2006 to 11-17-2006	12-15-2006 to 12-29-2006	01-23-2007	28
Summer 2007	02-15-2007	02-12-2007 to 03-23-2007	05-11-2007 to 06-12-2007	06-12-2007	68
Winter 2008	09-25-2008	10-16-2008 to 01-14-2009		01-14-2009	90

Hourly mean gaseous emissions (g N h^{-1} and g C h^{-1}) were calculated by multiplying the ventilation rate by the differences in gas concentration between indoor air and outdoor air.

Validation

Continuous measurements were validated by the comparison of the Cumulated Measured Emissions (CM Emissions) with the Mass balance Deficits (MD Emissions) as explained by Hassouna et al. (2008). For each volatile element (H_2O, C and N) the CM emissions should correspond to the MD emissions. Inputs were calculated by adding the quantity of N, C or H_2O in pig carcasses at the beginning of the fattening (Table 2) and those consumed by animals.

Table 2. Formula to calculate quantities of N, C and H_2O retained in animal carcasses

	Formula (CORPEN, 2003)
N retained	$e^{(-0.9385-0.0145 \text{ x Muscle content})}$ x $(0.915 \text{ x Body Weight (BW)}^{1.009})^{(0.7364+0.0044*\text{Muscle content})}/6{,}25$
C retained	BW x C (C = 200 g C/kg BW)
H_2O retained	BW x H_2O (H_2O = 600 g H_2O/kg BW)

Outputs correspond to the addition of quantity of N, C and H_2O retained in carcasses at the end of the fattening period (Table 2) and those contained in slurry. These last were calculated with the volume of slurry and the N, C and H_2O concentrations in slurry sampled during intermediate and final pit emptying.

Step 2: Comparison of carbon losses calculated with farm data (MD emissions) vs reference data.

The CRM relies on carbon mass balance (equation 6) that requires technical livestock data (slurry and diet compositions and quantities, animal weights). The carbon mass balance for each batch was calculated using the recorded technical livestock data and compared to the carbon mass balance calculated with reference data presented in Table 3. Using reference data would allow the simplification of the method by avoiding surveys in farms to acquire the technical livestock data.

$$\text{Carbon losses} = Q_{C,\ \text{carcass at the entry}} + Q_{C,\ \text{feed}} - Q_{C,\ \text{carcass at slaughtering}} - Q_{C,\ \text{slurry}} \quad (6)$$

where $Q_{C,\ i}$ is the quantity of carbon in i (i = carcass at the entry, feed, carcass at slaughtering, slurry).

Table 3. Reference data used to calculate the carbon mass balance

Nitrogen	Diet	Growing diets (40%)[1] : 16,5% Dietary Crude Protein[1]
		Finishing diests (60%)[1] : 15% Dietary Crude Protein[1]
	Animal	Muscle content[2] : 61,5
	Slurry	Quantity per pig[3] : 4,1 kg per day
		Composition[3] : 5,8 g N per kg
Carbon	Diet	Dry matter[4] : 87 %
	Slurry	Dry matter[3] : 6,84 %

CORPEN (2003)[1] , IFIP (2007)[2], Levasseur (2006)[3], INRA (2002)[4]

If the difference between carbon losses calculated with farm data vs. reference data is lower than 30%, we will consider that the reference data can be used to estimate carbon losses in our simplified method.

Step 3: Identification of the good periods, duration and frequency for spot gas concentration measurements

The setting up of the simplified method was based on the determination of frequency of measures, periods but also of the duration of each period necessary to obtain ratios of mean concentrations. These last will permit to obtain cumulated emissions, by using the simplified method equations.

To determine representative measurement periods, the kinetics of the concentration ratios obtained with continuous measurements were analyzed. Measurement periods were also chosen in relation to the practice applied, in particular for feeding strategy. Various days were examined and the emissions obtained for each analyzed day were compared to measured emissions.

Sampling duration was identified according to the same method already used to determine the measurement periods. An analysis of the kinetic of concentration ratios per day was achieved and sample duration chosen according to different technical criteria, but also according to the measurement feasibility. Gaseous emissions calculated with the chosen sampling duration were compared to measured gaseous emissions.

Step 4: Validation of the simplified method with an additional batch

An additional batch fed during a cold period (winter 2008) was studied to validate the different choices of measurement periods and duration. Cumulated gaseous emissions obtained with the simplified method were compared to cumulated measured gaseous emissions. If both emissions are equivalent then the simplified method can be regarded as representative.

RESULTS AND DISCUSSION

Animal performance

Pigs were slaughtered between 103 and 118 fattening days for the three batches with a final body weight heavier in summer (Table 4). The average daily gain (ADG) was higher for pigs reared during the 2006 and 2008 (839,1 and 840,9 g d^{-1}) than for those reared in summer 2007 (767,6 g d^{-1}). The negative effect of warm temperature on performance is commonly observed and explained by reduced daily feed intake (Quiniou et al., 2000). As commonly observed during cold times, the Feed Conversion Ratio (FCR) was higher in winter (2006 and 2008) than in summer because of thermoregulation need (Quiniou et al., 2000). In our experiment, for the three batches, zootechnical performances were in agreement with values already obtained in previous studies and representative of French pig breeding.

Table 4. Pigs Growth Performance

	Winter 2006	Summer 2007	Winter 2008
Number of pigs	60	60	60
Initial body weight (kg)	29,0	25,8	21,0
Final body weight (kg)	115,5	116,4	114,3
Body weight gain (kg)	86,4	90,6	93,3
Fattening duration (days)	103	118	111
Average daily gain (g d^{-1})	839,1	767,6	840,9
Feed Conversion Ratio (kg kg^{-1})	2,55	2,50	2,74
Growing feed (kg)	5771	6562	6213
Finishing feed (kg)	7445	7006	9126

Climatic conditions

Outside temperatures during winter and summer periods were representative of seasonal temperatures. Temperature varied from 3,5 °C to 19 °C during winter 2006, from 3,6 °C to 21,6 °C during summer 2007, and from 0,4 °C to 19,7 °C during winter 2008. Average indoor temperatures were respectively 23,4±1,8, 24,5±1,3 and 24,7±0,7 °C during winter 2006, summer 2007 and winter 2008. The average relative humidity was 78,8±8,8, 63,0±5,4 and 82,0±10,9 % for, respectively, winter 2006, summer 2007 and winter 2008, and 98,5±5.0 and 83,1±15,0 % for the outdoor relative humidity, during winter and summer respectively.

Development of the simplified method

Step 1: Gaseous emission measurements and validation

Table 5. Comparison of the Cumulated Measured Emissions (CM Emissions) with the Mass balance Deficits (MD Emissions)

Season	Winter 2006			Summer 2007		
Gas (*)	MD emissions	CM emissions	Difference (%)	MD emissions	CM emissions	Difference (%)
Nitrogen	72,2	59,6	-17,4	46,4	44,2	-4,7
Carbon	3736	4382	17,3	3870	3671	-5,1
Water Vapor	22747	22864	0,5	19703	15807	-19,1

The difference between gaseous emissions measured and calculated was lower than 25% (Table 5). In consequence, gaseous emissions measured were considered representative.

For the whole period of fattening, NH_3 CM emissions were respectively 10,8 and 9,12 g NH_3_N per pig per day in winter and in summer. For pigs reared on fully slatted floor, these values were in agreement with the literature (Hoeksma et al., 1992, Philippe et al., 2007). For N_2O, CM emissions were respectively 0,26 and 0,19 g N_2O_N per pig per day in winter and in summer. In similar conditions, Phillipe et al. (2007) published values around 0,3 g N_2O_N per pig per day.

For CO_2, CM emissions during the fattening period were 788,4 g CO_2_C and 637 g CO_2_C per pig per day for the winter and the summer batches, respectively. These values are lower than values cited by Philippe et al. (2007) and Gallman et al. (2003), with values ranging between 1,6 and 2 kg per pig per day. CH_4 emissions (7,4 and 10,1 g CH_4_C per pig per day for the winter and the summer period, respectively) agree with values proposed by Gallman et al. (2003 - between 6 and 9 g CH_4_C per pig per day).

Step 2: Comparison of carbon losses calculated with farm data (MD Emissions) vs reference data.

Difference between carbon losses calculated with farm data and reference data were -5,8%, 2,9% and 3,3% respectively in 2006 winter, 2007 summer and 2008 winter. These results are rather close because French pig production is standardized. These results validate the use of reference data to calculate the carbon mass balance using the CRM Method.

Step 3 Identification of the good periods, duration and frequency for spot gas concentration measurements.

The main goal of the simplified method is its application to a large number of farms. That's why the duration and the number of sampling periods must be limited. The concentration ratio analysis led to the choice of CH_4/CO_2 because of its stable evolution and the reliability of CO_2 measurements. The analysis of CH_4/CO_2 during the whole rearing period showed a linear response of this ratio as a function of time (R^2=0,72). That's why the number of spot measurements days has been fixed to 3. The choice of sampling periods had to integrate the modification of the feed management. Two diets were given to pigs during the fattening period: a first diet with a high level of crude protein given during the first 50 days of fattening and a second one with a lower level of crude protein until slaughtering. With regard to the recorded kinetics, sampling days which would permit to obtain a gradient of concentration ratio representative of the CH_4/CO_2 concentration ratio during the whole fattening period would be:

- The first day : between 15 and 25 fattening days
- The second day : between 50 and 70 fattening days
- The third day : between 80 and 110 fattening days

In winter, tested sampling days were at 25 and 60 days of fattening with a sampling duration of 24 hours. For the summer batch, 25, 60 and 80 fattening days were tested. Comparisons of gas emissions calculated by the simplified method (SM emissions) with those sampling days and CM emissions are presented in table 6. For both batches, differences are lower than 20%, except for ammonia for the winter batch. The use of only two days in the winter batch (25 and 60 days) is the main explanation of this result.

Table 6. Comparison of measured emissions (CM emissions) and those obtained with the simplified method (SM emissions)

Season	Winter 2006			Summer 2007		
Gas (*)	SM emissions	CM emissions	Difference (%)	SM emissions	CM emissions	Difference (%)
CO_2_C	3920,0	4341,0	9,70	3715,0	3624,0	-2,5
CH_4_C	33,2	40,7	18,4	40,7	47,0	13,4
NH_3_N	39,00	58,2	33,0	34,9	43,1	19,2
N_2O_N	1,43	1,39	-2,9	0,96	1,01	4,9
H_2O	18556,0	22864,0	18,8	13729,0	15807,0	13,2

(*) values in kg per room

Successive data treatments were used to determine the optimal duration for sampling gas during the chosen sampling day (d 25, d60, d80) (Table 7).

Chosen sampling periods from 10h am to 4h pm obtained SM emissions close to CM emissions with differences of 5%, 2,3%, -13,3%, -19,8% and -5% for H_2O, CO_2, CH_4, NH_3 and N_2O respectively in 2007 summer and -15,1%, -9,7%, -18,1%, -23,8% and 4,3% for H_2O, CO_2, CH_4, NH_3 and N_2O respectively in 2006 winter.

Table 7. Difference (%) between measured emissions with continuous method and measured emissions with simplified method basing on different sampling periods

	Winter 2006					Summer 2007				
	H_2O	CO_2_C	CH_4_C	NH_3_N	N_2O_N	H_2O	CO_2_C	CH_4_C	NH_3_N	N_2O_N
9h am-1h pm	-11,.9	-9,7	-17,6	-25,9	2,9	4,5	2,5	-13,4	19,8	-5,9
10h am-4h pm	-15,1	-9,7	-18,1	-23,8	4,3	5,0	2,5	-13,3	-19,8	-5,0
2h pm-6h pm	-27,4	-9,0	-18,9	-22,2	3,6	-18,4	2,.5	-13,2	-19,8	-4,9

Step 4: Validation of the simplified method with an additional batch

For validation, SM emissions were compared to CM and MD emissions during winter 2008. Average indoor and outdoor temperature was 24,8°C and 7,3°C. Average indoor and outdoor relative humidity was 82% and 93,3%.

The use of the simplified method with data of a third batch with 3 sampling days (d25, d60 and d80) during 4 hours from 2h pm and 6h pm leads to a difference between CM and SM emissions lower than 20 % for N_2O, CH_4 et CO_2, NH_3 et H_2O emissions (Table 8).

Table 8. Comparison of gas emissions obtained with the simplified method (SM emissions) and continuous measurements method (CM emissions).

Gas (*)	SM emissions	CM emissions	Difference between CM and SM emissions (%)
CO_2_C	3954	4680	18,4
CH_4_C	51,2	59,5	16,3
NH_3_N	40,2	45	11,8
N_2O_N	0,7	0,8	15,7
H_2O	23754	24370	2,6

(*) values are given in kg per room

The difference between SM and MD emissions was 18,3 and 20,1 % for carbon and nitrogen emissions, respectively. These results allow us to certify the good reliability of the simplified method elaborated in this study.

CONCLUSION

This study with fattening pigs reared on fully slatted floor developed a simplified method to assess ammonia and greenhouse gas emission factors. In our study, the difference between the cumulative measured (CM) emissions and simplified method (SM) emissions was less than 20%. This simplified method, based on intermittent gas concentration measurements can be achieved by sampling air three times during the fattening period (d25, d60 and d80) during 4 hours from 10h am to 4h pm. Because the kinetics of emissions differ between litter solid manure and slurry systems, this simplified method will have to be adapted to bedding systems. A measurement protocol has been constructed and recommends sampling materials and the sampling air method. To validate this protocol, measurements also will have to be performed on farms.

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