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FRENCH MINISTRY FOR HIGHER EDUCATION AND RESEARCH

Executive summary

REFERENCE PROCEDURES FOR THE MEASUREMENT OF GASEOUS EMISSIONS FROM LIVESTOCK HOUSES AND STORES OF ANIMAL MANURE

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1 Aim of the study

Gas losses in animal farms are taking an increasing importance in the media. The paradox of this tendency is the great number of publications, scientific or not, whereas the emissions of the majority of the animal farms were never characterized. The development of measurement tools for greenhouse gases and ammonia is thus of topicality. To quantify the emissions would also allow recognizing and even remunerating the environmental performance of animal farms. Thus, farmers would be incited to adapt their practices. They could propose realistic objectives of reduction, without waiting until negative effects are so high that aN expensive regulation becomes inevitable. Accordingly, ADEME funded an international project associating several organizations of research and development of the animal chain.

The objective of the project is to propose a first set of reference procedures for the measurement of ammonia and greenhouse gas emissions in the animal housings and manure stores, adapted to the diversity of the animal farms which can be met throughout the world.

2 Method

The project is based on the experience of the partners in the measurement of gas emissions in animal farms and on exchanges between them.

It comprises three phases. First is intended to review the methods and to choose those which are described more precisely. Second aims to compare various measuring methods by experiments with storage of liquid manure and in animal housing. The third phase is intended to evaluate the possibilities of application of the methods in various countries. Complementary projects in France, associating the French actors of ADEME project and Agricultural Schools of Brittany (CASDAR, PITE, RMT) made it possible to fund other work of measurement and complementary computer developments.

3 Results

3.1 Phase 1: review of existing methods

The measurement of emissions is always based on the observation of a variation of concentration (inside-outside) and of an air flow. The situations are multiple, ranging from a measuring chamber of a few square decimeters to an emitting area of several thousands of square meters. In all the cases, the results should be used with great caution because of strong bias being able to result from the heterogeneity of the concentrations of the source, of the possible presence of multiple air inlets and air outlets, all of them having different concentrations that can affect concentration gradient and/or ventilation estimates, of the temporal variability due to the variations of the climate or the evolution of the animals, of the disturbances being able to be caused by the measurement itself (« intrusive methods »). All these sources of error being difficult to control, it is preferable to check emission measurements systematically by confronting two independent methods.

Table 1. Methods considered within the project

Method	description (paragraph)	continuous measurements*	main source of uncertainty	control	types of use **
measure the mass balance deficit of a storage of manure	7.2	not	sampling, and analytical methods applied to samples	comparison with national references; comparison of the losses for contrasted elements (e.g. H_2O, C, N, P, K)	1-5
measure the emissions of ammonia (NH_3), nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2) of storages of liquid manure with dynamic chamber	7.3	yes	representativeness of the emissions within the camber compared to the liquid manure surface	comparison with the mass balance deficit of emitted elements (C, N, H_2O)	3-5
measure the emissions of ammonia (NH_3), nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2) of storages of liquid manure with a tracing gas (SF_6)	7.4	yes	temporal interpolation (unsuited direction of the wind); detection level of the gas concentrations	comparison with the mass balance deficit of emitted elements (C, N, H_2O) ; comparison with micrometeorological methods	1, 2, 4
measure the emissions from the mass balance deficit of carbon for an animal housing of pigs	7.5	not	temporal representativeness of the gas analyzes; representativeness of the data of mass budget	comparison with the mass balance deficit of emitted elements (C, N, H_2O)	3-5
measure the emissions from the mass balance deficit of carbon for a meat poultry housing	7.6	not	temporal representativeness of the gas analyzes, representativeness of the data of mass budget	comparison with the mass balance deficit of emitted elements (C, N, H_2O)	3-5
measure the emissions from the mass balance deficit of a laying hen housing	7.7	not	temporal representativeness of the gas analyzes, representativeness of the data of mass budget	comparison with the mass balance deficit of emitted elements (C, N, H_2O)	3-5
measure the emissions from the mass balance deficit of carbon of an animal housing for dairy cows	7.8	not	temporal representativeness of the gas analyzes, representativeness of the data of mass budget	comparison with the mass balance deficit of emitted elements (C, N, H_2O)	3-5

* "yes" means that measurement can be continuous or discontinuous; "not" means that measurement is necessarily discontinuous

** (1) regulatory use; (2) certification; (3) use for farm recommendations; (4) scientific use to understand the mechanisms of emissions; (5) educational use

Table 1 (suite). Methods considered within the project

Method	description (paragraph)	continuous measurements*	main source of uncertainty	control	types of use **
calculation of the gas emissions using continuous measurements and a model calibrated with intermittent measurements of concentrations for animal housings	7.9	yes	representativeness of the reference emission measurements; calibration of the measurements of ventilation and concentrations	comparison with the mass balance deficit of emitted elements (C, N, H_2O)	1-5
calculation of the ammonia emissions using continuous measurements and a model calibrated with intermittent measurements of emissions for storages of liquid manure	7.9	yes	representativeness of the reference emission measurements; correlation of the emissions with the data used for temporal interpolation (e.g. air and surface temperatures)	comparison with the mass balance deficit of emitted elements (C, N, H_2O)	3-5
measure ventilation with an anemometer in housings with mechanical ventilation	7.10	yes	calibration of the anemometer	heat productions of the animals	1-5
measure ventilation with CO_2 budget in animal housings whatever the ventilation type	7.11	yes	model of CO_2 production by the animals, variations due to diurnal changes	water budget of the animal housing; productions of total, sensible, and latent heat by the animals	1-5
measure the ventilation with the heat balance of the animal house	7.12	yes	model of heat productions of the animals, in particular regulations due to house temperature or changes due to animal activity	water budget of the animal farm; productions of total, significant, latent heat of the animal farm	1-5
measure the ventilation with a tracer gas (SF_6) in the animal house	7.13	yes	homogeneity of the inside and outside concentrations ; temporal variability of the concentrations when the ventilation is high	budget of water and C of the animal house; productions of total, sensible, latent heat of the animals	1-5
measure the emissions by using ventilation measurements in the animal house	7.14	yes	calibration of ventilation and gas concentration measurements; interpolation of missing data	comparison with models of water evaporation, CO_2 emission, heat productions	1-5

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Table 1 (suite). Methods considered within the project

Method	description (paragraph)	continuous measurements*	main source of uncertainty	control	types of use **
measure the ammonia emissions using the inversion of a stochastic Lagrangian model	7.15	yes	atmospheric stability; calibration of concentration measurements; interpolation of missing data	comparison with direct measurements	3-4
measure the ammonia emissions using the inversion of a Gaussian model	7.16	yes	atmospheric stability; calibration of concentration measurements; interpolation of missing data	comparison with direct measurements	3-4
generate a selected ammonia concentration and measure it by bubbling	7.17	not	stability of the solution in terms of temperature, pH, ammoniacal concentration, calibration of the chemical analyzes	analyzes by bubbling and gas analyser or colorimetric tubes	4-5
calculate the uncertainty of gas emission measurements of the animal housings or storages of manure	7.18	yes	interpolation of missing data; representativeness of the method	mass balance deficit for various volatile and nonvolatile elements (H_2O, C, N, P, K)	2,4

* “yes” means that measurement can be continuous or discontinuous; “not” means that measurement is necessarily discontinuous

** (1) regulatory use; (2) certification; (3) use for farm recommendations; (4) scientific use to understand the mechanisms of emissions; (5) educational use

3.2 Phase 2: experimental comparison of the methods

3.2.1 Animal house measurements

Figure 1. General outlook of the poultry house

The continuous or intermittent measurements, direct (tracing with SF_6, heat production or CO_2) or indirect (Lagrangian or Gaussian reverse modelling), were compared in a house located in a flat area, without major obstacle around the house and without other sources of ammonia or particles (Figure 1), during the fourth week of a broiler flock, during the cold season where highest ammonia concentrations inside the house are expected.

Measurements of ammonia concentration outside the house show both a high temporal variability (Figure 2) and space variability (Figure 3), the latter not depending only on the distance to the house.

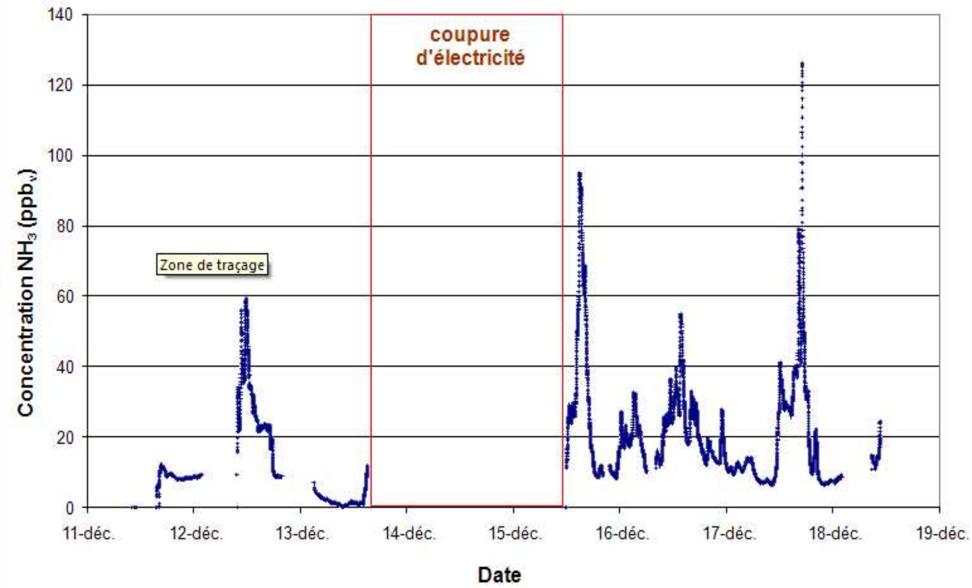

Figure 2. Ammonia concentrations observed at 60m from the house with a fotoacoustic analyser

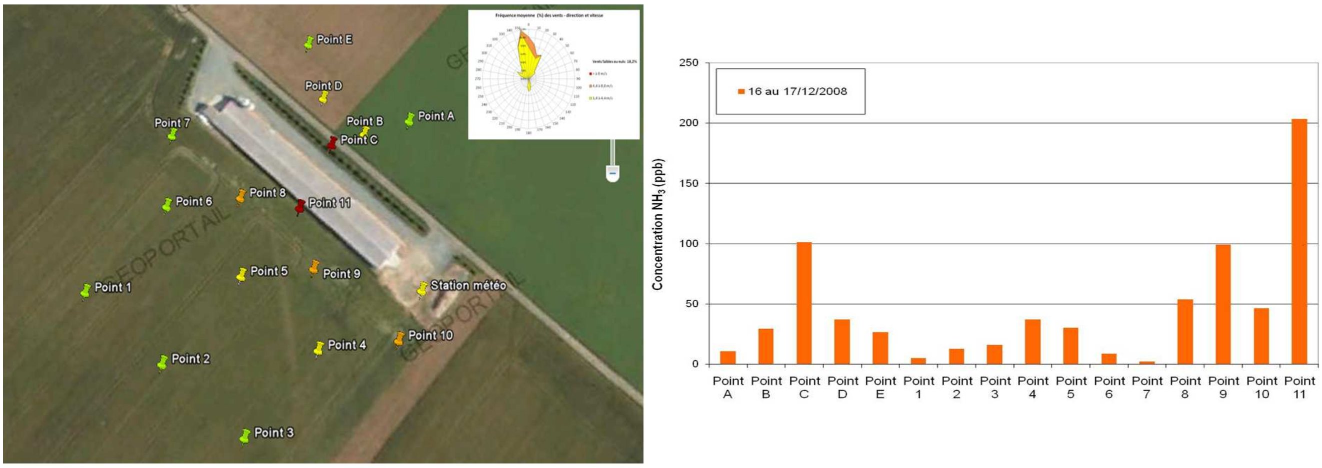

Figure 3. Average ammonia concentration observed during 24h (Dec. 17th 2008) with passive samplers

Direct emission measurements indicate the same order of magnitude whatever the method is tracing with SF_6 or with total heat. The emission measurement calculated with the Gaussian model using average concentrations observed around the house (Figure 3) gives a value of 69 ± 18 mg NH_3 s^{-1}, slightly lower. The emission measurements calculated with the Lagrangian model using the continuous concentrations gives lower values (method BLS, Figure 4). Ammonia sink by the vegetation cannot explain the difference of 50 mg NH_3 s^{-1} at 60m from the house (fluxes higher than 2000 kg N ha^{-1} $year^{-1}$). This comparison emphasizes the need of a better control of the observed fluxes and to associated uncertainty calculations with the measurements of emission fluxes.

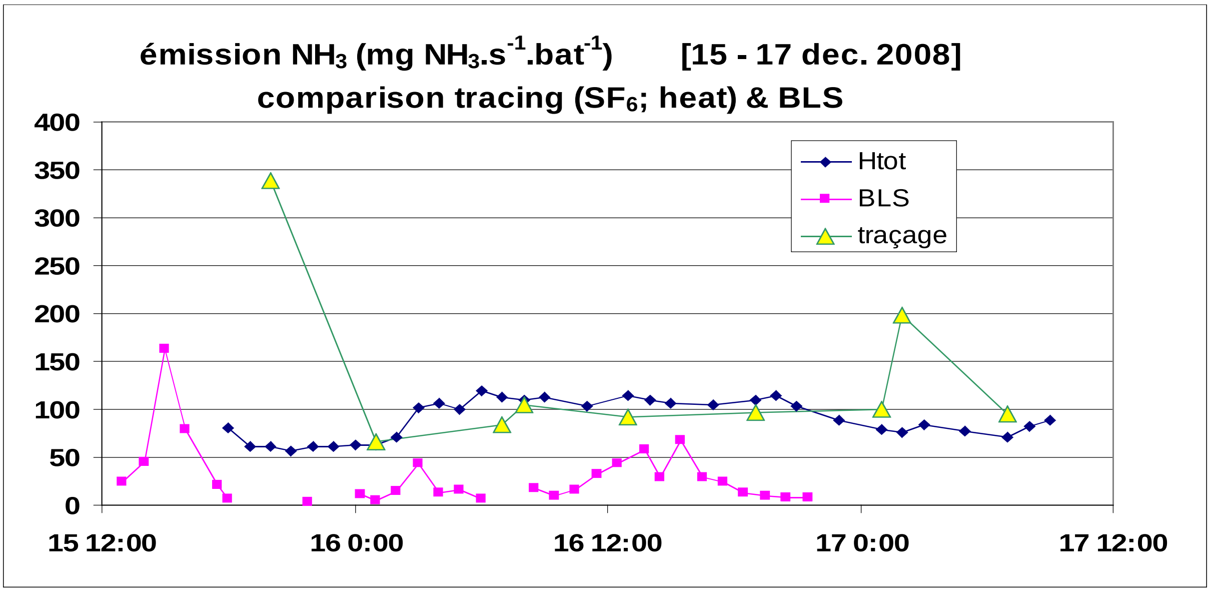

Figure 4. comparison of emissions measured by two direct methods and one reverse modelling method

Mass budget and intermittent measurements can be used together sometimes to estimate emissions (Table 2).

The carbon emissions measured by tracing with the total heat production are very close to the mass balance deficit. One can deduce from it that the ventilation estimated by tracing was close to the true value of ventilation.

The methane loss observed is slightly negative (methane sink). Before using this result, it is advisable to make sure that the detection level of the method makes it possible indeed to detect this value.

The difference between the measurements of water emission is very high. These differences can be explained by problems of sensor calibration. We used the calibration of the manufacturers, therefore, this calibration has to be checked as well as the connection of the calibrations of various equipment between them.

Table 1. Comparison of emissions observed with an intermittent method [concentration ratio] to the emissions observed with the tracing method using the heat production of animals, and to the deficit of the mass budget

kg /house	Mass budget	Htot continuous /tracing	Conc. Ratio
E H_2O	161005	207245	90044
E Carbone	**20004**	**22406**	**20004**
E C-CO_2		22436	20018
E C-CH_4		-30	-14
E Azote	**771**	**442**	**322**
E N-N_2O		167	17
E N-NH_3		275	306

The deficit of the nitrogen mass balance is higher than the emissions observed by direct measurements. This difference can be explained by a nitrogen loss as N_2. The solid manure was wet, aerated and rich in nitrogen and carbon, that is favorable to transformations by nitrification and denitrification. The emissions of NH_3 measured by the continuous method or by the simplified method give similar values. The emission measurements of N_2O are very different. The simplified method underestimates by 90% the emission observed by the continuous method. The emission of N_2O measured by the continuous method is close to 60% of the NH_3 emission. This result is very high compared to the usual data of the literature. It is probable that the observed broiler flock was not representative of standard broiler flocks for this flux. The continuous observation of concentrations during the flock shows that the choice of the measurement days for the simplified method leads to a bias: the periods with strong emission, at the beginning and at the end of the flock, were not sampled. Consequently, in the situations presenting a risk of increased emission of N_2O the sampling strategy of the batch must be checked by continuous measurements.

3.2.2 Measurements during storage of liquid manure

The period of storage experiment began in June and ended in September 2009, under wet and stormy climatic conditions at the beginning, warmer at the end of the experimentation.

Measurements carried on two pits (Figure 5), one exposed to the bad weather, characterized by tracing, the other under a plastic greenhouse ventilated with a flow known with accuracy.

The two pits were equipped with dynamic chambers and a budget of mass was carried out on each one.

Size : Ø 2.9 m x 2.0 m	**Size : Ø 3.5 m x 1,5 m**
6.6 m² surface	**9.6 m² surface**
Depth : 1.40 →1.28 m	**Depth : 1.40 →1.18 m**
Initial volume of slurry : 9.2 m³	**Initial volume of slurry : 13.4 m³**
Measurements : tracer, MB and chamber	**Measurements : closed area, MB and chamber**

Figure 5. Characteristics of the two tanks

The comparison of measurements by chamber and tracing on methane for the outdoor tank (Figure 6) shows a difference in the order of magnitude of emissions (chamber < tracing) and a difference in dynamics (increase in the emission measured by the chamber, stability of the emission observed by tracing). This result confirms other work showing that the ammonia emission of the room modifies the processes of gaseous emissions at the slurry surface. Consequently, if the accuracy of measurements by chamber is high (control of the air flow, representativeness of the gas samples, area of emitting surface), their representativeness can be low.

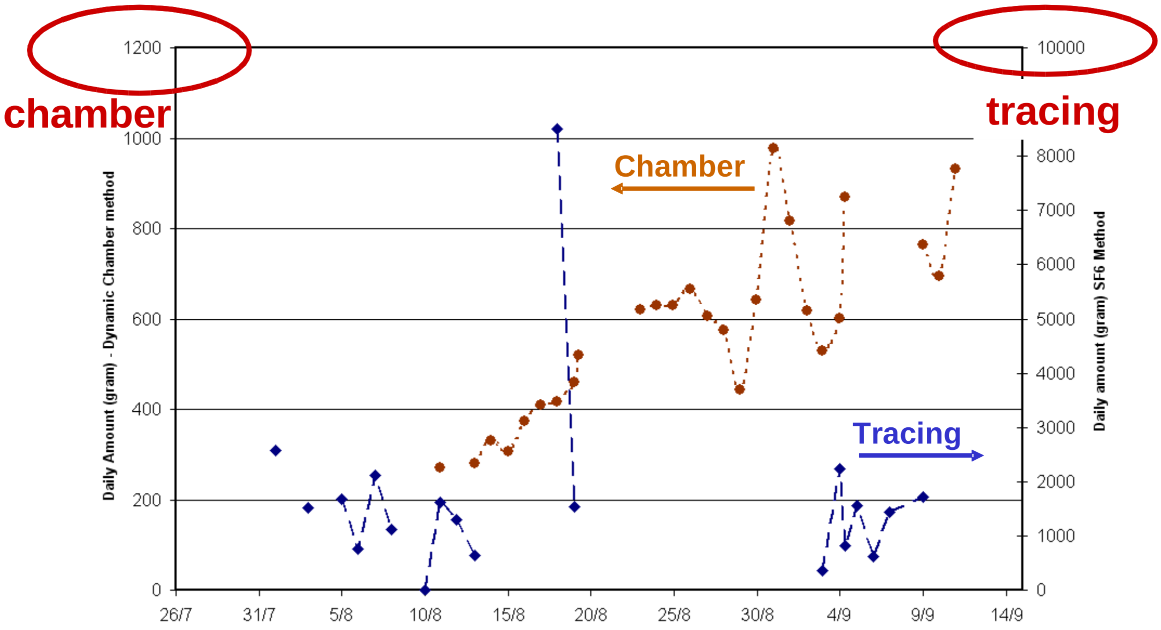

Figure 6. ***CH_4 emissions of the outdoor tank***

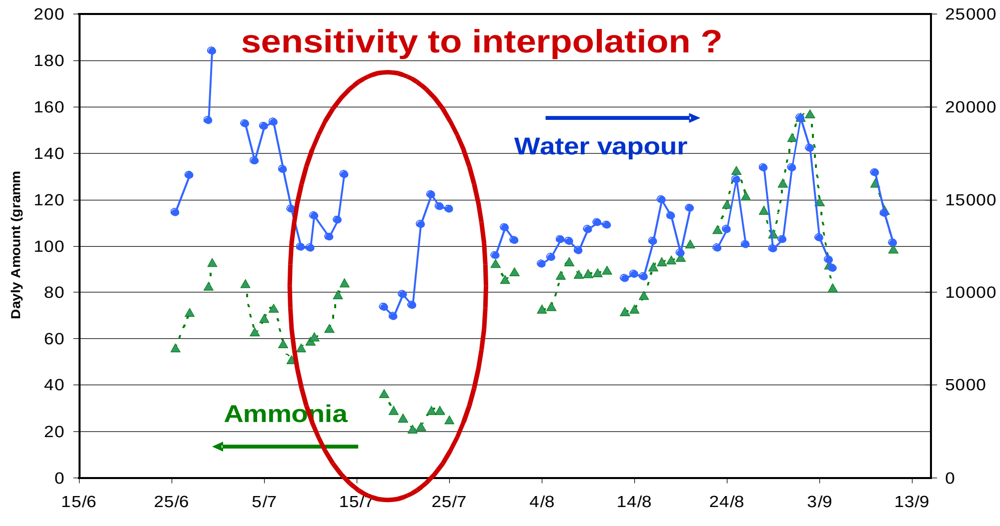

Figure 7. ***NH_3 and water emissions of the covered tank***

On the covered tank, the observation of the NH_3 and water emissions shows periods where measurements are interrupted (Figure 7). These periods correspond to failures of the system. These failures can occur in most experiments for accidental reasons (storm) or technical (inappropriate direction of the wind for tracing).

In this case the interruptions take place whereas the emissions strongly vary. It results from it a strong sensitivity of the cumulated emission to the choice of algorithm used to interpolate the data.

Uncertainty on the ammonia emission was calculated over a one month period, in the case of the covered tank, for which the ventilation of the greenhouse could be observed with accuracy. The ammonia emission over this period was 3,4 kg NH_3 for the tank. The measurements are figured for ammonia emission by ER g hr^{-1}, total exhaust ventilation rate by V_T m^3 hr^{-1}, temperature of the exhaust air by T_e ℃ , ammonia concentration by C ppmv.

The standard uncertainty in exhaust air temperature $u(T_e)$ ℃, standard uncertainty in ventilation rate $u(V_T)$ m^3 hr^{-1}, and standard uncertainty in the ammonia concentration u(C) ppmv are calculated from the standard deviation of the exhaust air temperature T_e, total ventilation rate V_T, and ammonia concentration in the exhaust C, respectively.

From the measurements: $u(T_e) = 0.2$ ℃ ; $u(V_T) = 45$ m^3 hr^{-1} ;u(C) = 0.12 ppmv.

The relative uncertainty u(ER)/ER is shown in Figure 8, and can be calculated from the following equation:

$$\frac{u(ER)}{ER} = \sqrt{\left(\frac{u(V_T)}{V_T}\right)^2 + \left(\frac{u(C)}{C}\right)^2 + \left(-\frac{u(T_e)}{T_e}\right)^2}$$

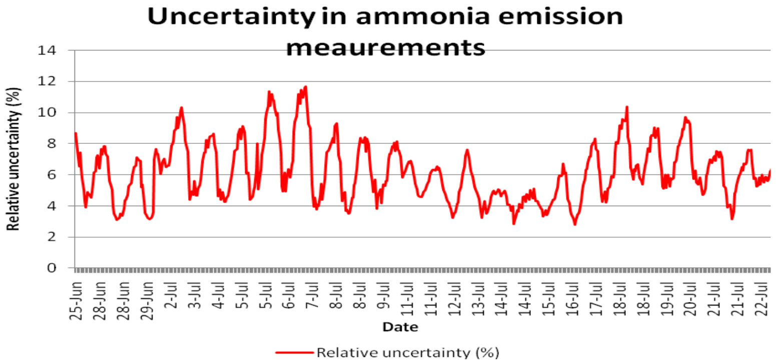

Figure 8. relative uncertainty on ammonia emission during one month

These values are very low (<10%) compared to the differences between methods mentioned above.

The comparison of the emissions to the deficits of the mass balance for carbon and nitrogen (Table 3) shows that the ammonia emission measured by the chamber is always lower than the nitrogen deficit. We retain the assumption of an important experimental bias, being able to exceed 90% of the “true” ammonia emission. Most of this uncertainty is due to the representativeness of the measuring equipment and to interpolation of missing data. These two points were not included in the uncertainty calculation presented above.They should be included to have a “true” estimate of the possible gap between observed value and “true” value.

Table 2. comparison between observed emissions and deficit of mass budget

		initial		final		deficit of mass budget (kg)	chamber measurement (kg)	tracing measurement (kg)
		content (g/kg brut)	mass (kg)	content (g/kg brut)	mass (kg)			
outdoor tank	*depth*	*1,400 m*		*1,28*				
	organic matter	*51,6*	*477*	*24,3*	*205*	*272*	*120**	*444**
	total nitrogen	*5,54*	*51,2*	*4,04*	*34,1*	*17,1*	*2***	*-*
covered tank	depth	1,400 m		1,185 m				
	organic matter	44,2	595	26,1	297	298	840*	-
	total nitrogen	5,01	67,5	4,38	49,9	17,5	6,4**	-

*CH_4 + CO_2 ; hypothesis C=OM*0.5

** NH_3 (other species are neglected)

1.1.1 Conclusion of the experimental phase

The experimental phase of comparison of the methods in the house on the one hand, with the storage of slurry on the other hand showed important differences between methods, whether it is in the house or with storage. It is thus advisable to be particularly careful in the use of results deduced from only one method, and not confirmed by a second method applied independently. By increasing the number of measurements in animal farms (temporal representativeness) and implementing complementary methods (absence of experimental bias), one can distinguish between animal farms either highly or weakly emitting. Mass budget of the animal farm, deduced from measurements or references on the animals, their food and their manure can be used as boundaries for emission measurements. Thus, three levels of quality can be distinguished: (I) the qualitative evaluation compared to a reference; (II) intermittent measurement with a risk of bias; (III) continuous measurement with a risk of error that is minimized in so far as the device of measurement does not interfere with the processes of emission.

3.3 Phase 3: evaluation of applicability

The possibilities of application of the methods was assessed in France, Belgium, United Kingdom, U.S.A., Brasil, and China. It shows the diversity of the national situations in terms of concern, and the difficulty to quantify uncertainty of measurements in animal farms.

However, field application of the methods is ongoing in many countries. Methodological work and international exchanges should thus continue, parallel to measurements in animal houses and manure stores, in order to harmonize the methods, to standardize some of them, progressing towards a certification of the emissions, while improving the knowledge of the real emissions of the animal farms. The appropriation of these results by *livestock industries will allow them to propose reduction goals based on their possibilities of measuring real emissions and their economic outlooks.*

4 General conclusion

This project made it possible to amplify exchanges in France and with foreign partners in order to propose a first set of reference procedures for the measurement of gas emissions in animal farms. These exchanges showed that the simplified measurement of the emissions, based on a mass budget of the animal house and the regular measurement of the concentrations inside and outside the houses, constitutes one of the rare low cost methods that can be used whatever if the animal houses are naturally or mechanically ventilated.

In addition to the procedures, the data observed in commercial conditions and the comparison of the methods showed at which point emission measurements in animal farm missed reliability and repeatability.Thus, associating independent emission measurements seems to be necessary to control the reliability of observed results.

For as much, the quality of the work carried out is not called into question. Theoretical and experimental work emphasized fundamental stakes of the measurement of diffuse emissions. Indeed, if measurement is reliable when the emission is channeled, it becomes it less and less as the system becomes more open and more sensitive to the influence of the climate or unforeseeable modifications in the behavior of the herd.

Thus the estimate of the uncertainty associated to the measurements seems the major lack of the previous published references and the major stake of the next years for the measurement of emission factors. Simple to calculate when measurements are continuous, equipment is well calibrated, the devices of measurement are not-intrusive, the estimate becomes delicate when it is necessary to evaluate the representativeness of space sampling (measurements by chambers) or temporal (intermittent measurements). The systematic calculation of the mass budget of the batch of animals appears as the most robust point, making it possible to avoid aberrant values of emission. The continuation of the exchanges between the partners to improve calculations of uncertainty is desirable.

All results, that is about fifteen procedures described in French and English, observed measurements, developed calculation programs and their documentations in French, will be available on a website at the end of the year 2010.