Emissions of Gas and Dust from Livestock

Edited by
Mélynda Hassouna and Nadine Guingand

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Preface

This book of proceedings contains all 99 papers presented (as oral presentations and posters) during the International symposium on EMIssion of gas and dust from LIvestock (EMILI 2012). This event took place from June 10-13, 2012, in Saint-Malo, France, and was organized by the French partnership network on livestock and environment.

The main purpose of this symposium was to provide state-of-the-art research on gas and dust emissions from livestock and also to bring up hot topics and relevant scientific questions. For the first time, scientists interested in livestock gas and dust emissions were able to meet in the same symposium.

During the event, keynote speakers presented in plenary sessions the general issues surrounding gas and dust emissions and the potential use of available knowledge.

The conference was organized around six parallel sessions focusing on relevant topics: modeling, emitting processes, measuring methods, emission factors, mitigation strategies and environmental evaluation. One hundred forty-seven participants from 27 countries attended this event and had access to 72 oral presentations. Exchanges also occurred during the poster session, which exhibited 39 posters.

Based on the scientific exchanges and presentations during the symposium, some important conclusions can be made. First, quantification of the uncertainty in measured emissions cannot be overlooked when evaluating the efficiency of mitigation techniques or comparing results from the literature. Second, internationally standardized methods adapted to different breeding conditions (climate, management practices, animal species, etc.) need to be developed to compare literature results and national inventories. At this level, international consensus needs to be developed to choose the appropriate methods.

These proceedings are the final step of the first edition of EMILI. For attendees, this book is a good way to improve understanding and serve as a reminder of information presented during the conference. For others, this document will be a new wealth of knowledge about gas and dust emissions.

Finally, we would like to warmly thank all contributors for the success of this event:

- the attendees, for their presence, interests and positive attitude,

- the organizing committee, for its logistic management and the communication process,

- the scientific committee, for the scope of the symposium, the reviewing process and the selection of the papers,

- the sponsors: INRA, DGER, Région Bretagne, Rennes Métropole, ADEME, DSM, Autochim, SPACE, GPB Environnement, CIV, CNIEL, IFIP, IDELE, CRAB and ITAVI

- Monique Delabuis, Manuela Pinel, and Michelle and Michael Corson, who contributed to the preparation of this book

Mélynda Hassouna and Nadine Guingand

International symposium on EMIssion of gas and dust from LIvestock (EMILI 2012)

June 10-13, 2012, in Saint-Malo, France

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Part I.
Emission factors

STATE OF DUST PREVAILING IN A POULTRY BUILDING OF LAYING HENS IN A SEMI-ARID REGION (NORTHEAST ALGERIA).

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ABSTRACT: One of the main environmental problems faced in poultry farming is the air in poultry buildings is dust-polluted. Our aim is to evaluate the state of dust prevailing in a poultry building.
The experimental research was performed during the 2008-2009 winter in an area near Batna, Northeast Algeria. It occurred in a poultry building containing laying hens kept in conventional coops with a breeding capacity of about 14,400 hens. This experiment comprises two studies:
The first study revolves around passive trapping of dust, which consists of mere trapping. For this purpose, special equipment based on two levels was established and used to cover the whole building.
The second study concerns active trapping of gathered dust. Particular equipment was implemented to capture the dust present at different levels: 44cm, 80cm, 116 and 153cm.
The dust gathered owing to four devices placed at different places of the building. In regard to the four heights mentioned, it was possible to obtain dust amounts whose weight was measured and characteristics identified.
The results obtained from the first study revealed that not only the amount of dust gathered is higher at 0.90m above the ground than those obtained at 2.10m, but also a gradient, running from the entrance to the back of the building, was more significant at 2.10m from the ground.
The second study results revealed that the gathered dust ranges from 0.051 to 0.346mg/m^3, and that dust tends to migrate to the back of the building depending on the door being opened or closed. The results also revealed a significant concentration of dust present at 116cm above the ground.

Keywords: dust, poultry farm, hens, semi-arid region, Northeast Algeria

INTRODUCTION: Assessing the effects of agricultural practices on air quality requires the definition of major air pollution linked to those above. These are numerous and diverse. (Takai.H. et al., 1997) classifies each of their scope and function: short and medium distance odors, dust and toxic gases; long-range (transboundary) acid and photo-oxidative pollutions, which affect global changes and aggravate greenhouse effects.

Agriculture, in general, contributes to the emission of many pollutants and dust is among these. The latter, whether primary or secondary particles, emerge from farms and agricultural soils (Federal Commission for Air Hygiene (CFHA), 2007), or from food industries, which are among the main sources of anthropogenic stationary particles (Federal Commission for Air Hygiene (CFHA), 2007). Handling food products, such as grain, meal and pellets, creates large quantities of dust. (Lelercq.S., 2002).

Breeding livestock in buildings raises air quality issues, which consists of pollution by gases and dust particles. Among these is organic dust containing high levels of lipopolysaccharide (LPS). These LPS cause acute and chronic bronchial obstruction in swine, poultry and grain workers (Caillaud.L. et al., 1996).

Algerian poultry farming has known great development in recent years. Many regions have made significant investments in the sector, following the growing demand for poultry products, which is not without environmental consequences.

The study focuses on the dust in a poultry farm of laying hens in production conditions. The aim is to quantify the rate of dust emission and to understand which areas of the building contains a greater concentration of dust.

1. MATERIAL AND METHODS:

1.1. The breeding of laying hens: The experiment was performed in a building of laying hens, containing 14,400 Hy-line hens. These hens are kept in cages (four hens per cage) forming three batteries "A " shaped of three stages on each side. The building is filtered with four air extractors situated at the far end of the building and two humidifiers situated in the middle of two side walls. (Figure n°1). The composition of food used for the breeding is constituted as follows: 60% corn, 20% soya, 1.5% CMV (supplementary benefit mineral and vitamins), 10% rough brain, 7% limestone and 1.5% Phosphate bi calcic.

1.2. The dust collection: Dust collection was performed in two ways:

1.2.1. The passive way (static): This consists of a dust collection gravimetrically. The dust settles under the effect of its weight in eighty boxes (0,090; 0,140; 0,055 m) distributed along walkways, spaced 6m apart between the batteries of two levels : At level 1: 0.90 m boxes are attached to batteries and level 2: 2.10 m boxes are suspended from the roof of the building (Figure n° 1). The dust is collected from the boxes once a week and weighed. The study lasted five successive weeks (5 tests).

1.2.2. The active way (dynamic): This consists of the air passing through a filter and weighing it before and after the forced capture of the sample. The amount of dust is expressed in mg/$m^{3.}$ This method was inspired by the literature (Federal Commission for Air Hygiene (CFHA), 2007) describing the gravimetric procedure as the reference method. In this second study we conducted eight tests, each test lasting 30min. Capture is performed as follows:

- Four drivers made specifically for the study were used for the collecting.
- The filter weight is weighed before and after each test.
- The dust captured is characterized after each test.

For this study we used equipment consisting of 4 drivers. Each one is a hermetic assembly of pipes and funnels forming the dust sensors and are arranged on four levels. Each level includes: A funnel filtered with a sponge, as a first filter capped with a second filter, is made of black material, and the whole device is enclosed under the perforated lid of the funnel, which itself is a third filter .

The four sensors, spaced 0.40 m apart, and at the same distance from the ground, are connected by a pipe 0.60m long and 0.02m in diameter to a vertical main pipe. These sensors are arranged around it in a helix forming a 90° angle with each other. Each

driver, maintained by a metal bracket, is connected to a meter for measuring the air volume of air passing through the pilot sucked by a vacuum attached to the end of a 0.040m diameter pipe.

In each test, the weight of the filter is weighed before the test, then the four drivers are placed at the ends of path 2 and 3 (Figure. 2), and the four vacuums are activated for 30min. Once testing is completed, the receiver filter is weighed again in the laboratory. The weight of dust collected is obtained in mg. Next, we determine the volume of air in m^3 per level. Thus, we express the amount of dust captured by the level in $mg/m^{3.}$

After determining the weight of the dust, the content of the receiver filter is carefully saved in the molded box blank. The lid of the box has a molded template. This is a 16 millimeter sheet suggesting lights, ^{two} 25mm ^{square,} divided into two perpendicular radial lines, the lights are spaced 0.01m apart. The observation of dust particles in the box occurred under a microscope with x10 G magnification through the lights of the template. The sixteen observations correspond to one sample per level to be used for physical characterization of dust particles at this level. For each observation, using the image processing software "Motic image +", we get the surface (microns square) and perimeter (microns) minimum means; maximum of all particles in the observed field. At each level we make a sample; therefore, when processing the results we consider the medium value of sixteen observations for each parameter.

2. RESULTS AND DISCUSSION:

2.1. Results of the passive capture of dust: The amounts vary between 0.05 and 1.68g of dust by 0.0126m (3.97 and 133.33g/m²) for Level 1 (harvested at 0.90m from the ground), and between 0.0092g and 0.61g 0.0126m (0.73 and 48.41g/m) for the dust level 2 (2.10m harvested from the ground). This reveals a considerable amount of dust higher than 0.90m to 2.10m from the ground. At the height of 0.90m, corresponding to half way up the battery, all the dust is generated from either the movement of poultry or the activity of the workers during food distribution. These differences between the two levels are confirmed by the ANOVA results and are highly significant for all five tests. In all combinations studied, the variation trend curves of average values of quantities captured at the height of 2.10m above the ground and along the building increase from the entrance to the back of the building. These results show a larger amount of dust in the building. This accumulation is probably due to air extractors located in the far end of the building, which draw ambient air to the bottom. This important phenomenon in path 2 is due to the door of the building, which is opposite the start of the walk, which amplifies the displacement of dust to the rear of the building.

2.2. Results obtained during the second study:

2.2.1. Weight of Dust: The dust proportions measured during this second study are between 0.051 and 0.346 mg/m^3. Our results fall within the range of values mentioned in literature. Thus, (Miehel V. et al., 2007) measured concentrations between 0.15 and 0.18 mg/m^3 for laying hens in cages, and between 2.12 and 0.74 mg/m^3 for laying hens in aviaries. (Fabbri C. et al., 2007) measured in a barn of laying hens in cages, concentrations ranging from 0.105 to $0021mg/m^3$ for $PM_{2.5}$, and between 0.381 et 0074 mg/m^3 for PM_{10}.

Statistical analysis of our results demonstrated that only two pilots and four located in the third lane (the second driver placed at the front and the fourth driver in the back of the aisle) have significant results, this supports the idea that there is a shift of dust to the rear of the building due to the air stream created by the action of the extractors. This statistical study revealed that the 3rd level (1.16m) of each driver, and for each of eight tests, shows highly significant results. At the height of 1.16m above the ground, the bulk of dust is concentrated probably due to the workers' various activities (cleaning, egg collection, food distribution) but also by the beating wings of hens, which blow on fine particles of food and cause them to rise.

2.2.2. Characterization of dust collected: The six parameters we considered in this characterization of collected particles: the medium surface, the maximum surface, minimum area, average perimeter, maximum perimeter and minimum perimeter, have mixed results. In both ANOVAs performed:

Analysis of variance for each parameter based on the levels and testing for each driver shows significant differences between the values of each parameter for the factor test. However, for the factor level, only pilot1 shows significant differences between the values for each parameter, and parameters for pilot 4: Smin, Smax; Pmin.

Analysis of variance for each parameter according to the pilots and tests for each level shows significant differences between the values of each parameter to test the factor, but for factor level 1 only the pilot has significant differences among the values of five parameters, except Smax, and the level 2 for the parameters: Smin; Pmax; Pmean. For level 3, only the parameters Smoy; Smax; Pmean; Pmax are concerned.

Despite the existence of significant differences between the values of each parameter considered for the factors studied, we were not able to classify these values because they overlap and do not allow us to conclude.

CONCLUSION: The results obtained in the first experiment involve passive dust collection and reveal higher amounts of dust at 0.90m than at 2.10m from the ground. A displacement of the dust toward the back of the building shows an effect (input/far end) at 2.10m from the ground. This effect is more enhanced in path two facing the front door. The results of the active dust collection at different heights (44cm, 80cm, 116cm and 153cm) have shown that dust collected ranges between 0.051 and 0.346 mg/m^3 have a more significant concentration of dust at 1.16m above the ground, and a movement of dust to the bottom of the building. It is clear that hens placed at the height of 1.16 m and the far end of the building are those most exposed to dust.

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APPENDIX :

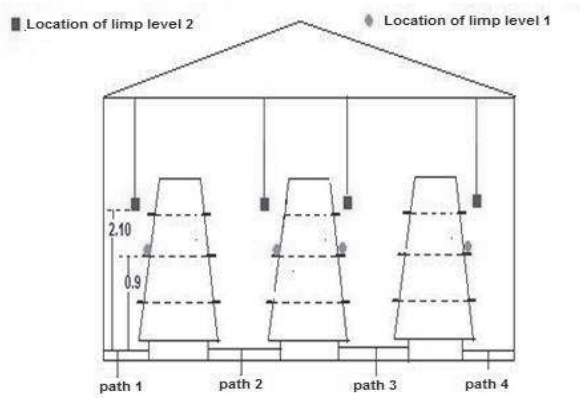

Fig 1. Location of limp, transverse view (Passive way)

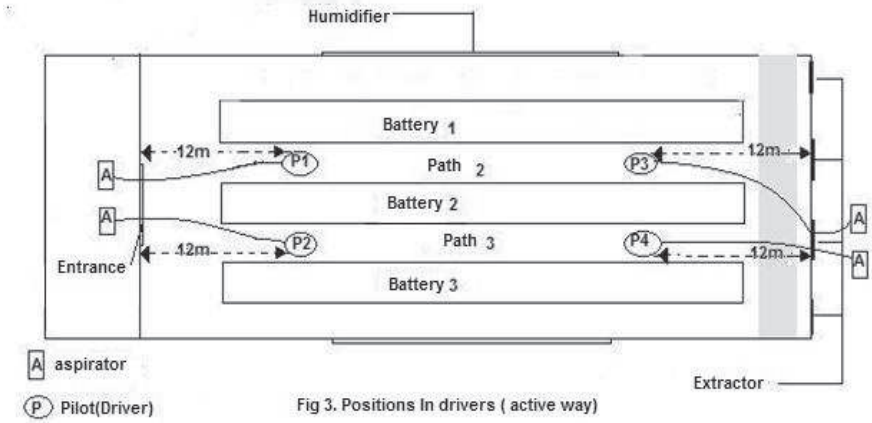

Fig 3. Positions In drivers (active way)

AIR EMISSIONS FROM DAIRY OPERATIONS: A LITERATURE REVIEW

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ABSTRACT: Dairy emissions data for pollutants other than ammonia have been lacking, but gaps were recently filled by the National Air Emissions Monitoring Study (NAEMS), which provided the most comprehensive and consistent emissions data set. Average NH_3 emissions measured by the NAEMS ranged from 23.1 to 36.0 g/d per 500 kg live mass (AU) compared with 1.1 to 98.4 g/d-AU in the literature. Average H_2S emissions in the NAEMS ranged from 401 to 7162 mg/d-cow. The annual mean $PM_{2.5}$, PM_{10}, and TSP emissions measured at four NAEMS dairy farms ranged from 26 to 588 mg/d-hd, 82 to 1225 mg/d-hd, and 405 to 3713 mg/d-hd from confined freestalls. The review of VOC emissions included specific VOC compounds. The most predominant VOCs in the NAEMS were n-propanol, ethyl acetate, iso-propanol, n-propyl acetate, and acetaldehyde. Freestall barns in the NAEMS emitted an average of 34 to 197 g/d-hd of total VOC. Mitigation techniques for NH_3 include reducing N excretion through dietary manipulation, reducing volatile NH_3 in the manure, and segregating urine from feces using sloping floors.

Keywords: NH_3, H_2S, PM, VOC, dairy cattle

INTRODUCTION: Reported air pollutant emissions from dairy farms was reviewed and compared with data collected from the recently conducted National Air Emissions Monitoring Study (NAEMS) (Heber et al., 2011).

AMMONIA: Measurements of NH_3 at dairy facilities using modern methods started in the early 1990s and multinational emission measurement studies were conducted in Europe in the 1990's (Groot Koerkamp et al., 1998) and the U.S. in the 2000's. The most recent review of dairy NH_3 emissions was conducted by Hristov et al. (2011). Emission models have been used to evaluate mitigation strategies, including diet modification (Monteny and Erisman, 1998); Rotz and Oenema, (2006), and to study the effects of temperature on emission rates (Adviento-Borbe et al., 2010). Danish models use an NH_3 emission factor of 5% of excreted N for cows in a tie-stall, and 10% for a freestall (Pedersen, 2006). Simulations (Rotz and Oenema, 2006) comparing the two barn types gave cow-specific NH_3 emission rates of approximately 16 and 37 g NH_3/d for lactating cows in tie-stall and freestall systems.

Hristov et al. (2011) compiled NH_3 emission rates ranging from 0.82 to 250 g/d-hd (mean=59 g/d-hd). Variations in the literature occur, in part, because emissions are higher in warm weather Kroodsma et al., (1993); Harper et al., (2009). The long-term live mass specific NH_3 emissions measured at NAEMS sites NY5B (Bogan et al., 2010), IN5B (Lim et al., 2010), WI5B (Cortus et al., 2010) and WA5B (Ramirez et al., 2010) were mid-range (Table 1). Average whole farm cow-specific NH_3 emission rates ranged from 8.8 g/d-hd in winter to 100 g/d-hd in summer (Flesch et al., 2009). Battye et al. (2003) recommended an NH_3 emission factor of 76.7 g/d-cow.

Table 1. Ammonia emissions from dairy freestall barns reported from selected studies.

Vent	Loc.	Manure collection	Season	Emission, g/d•AU	Reference
NV	DE	Scrape	SU	98.4	Fiedler and Müller, 2011
NV	DE	Scrape	W	40.3-85.4	Snell et al., 2003
NV	DE	Pit/flush	W	38.8-57.1	Snell et al., 2003
NV	NL	Pit/flush	W-Sp	25.8-40.4	Kroodsma et al., 1993
MV	NY	Scrape	All	36.3±18.1	Bogan et al., 2010
MV	IN	Scrape	All	36.0±21.6	Lim et al., 2010
MV	WI	Scrape	All	28.0±12.6	Cortus et al., 2010
NV	WA	Flush	All	27.5±19.1	Ramirez, et al., 2010
MV	WI	Flush	All	23.1±6.13	Cortus et al., 2010
NV	SE	Scrape (2X)	All	26.4± 9.6	Ngwabie et al., 2009
NV	WI	Scrape	Fall	6.6–32.0	Harper et al., 2009
NV	PA	Scrape (2X)	All	18.7-30.1	Adviento-Borbe et al., 2010
NV	ENG	Scrape (2X)	W	6.0	Phillips et al., 1998
NV	VA	Flush (4X)	--	1.1–3.6	Li et al., 2009

HYDROGEN SULFIDE: The NAEMS provided the first long-term measurements of H_2S emissions from dairy housing. Average H_2S emissions measured by the NAEMS ranged from 401 to 7162 mg/d-cow (Table 2).

Table 2. Dairy freestall barn H_2S, PM and VOC emissions (mg/d-hd) measured by the NAEMS.

Site	H_2S mg/d-hd	$PM_{2.5}$, mg/d-hd	PM_{10}, mg/d-hd	TSP, g/d-hd	VOC g/d-hd
NY5B (scrape)	964±1137	69.9±187	420±1271	0.420±1.33	197±125
IN5B (scrape)	1065±522	25.9±146	82.1±267	0.405±0.368	34.0±26.2
WI5B (flush)	7162±5373	588±616	1225±2129	3.71±4.02	N/A
WI5B (scrape)	401±358				67.9±38.9
WA5B (flush)	1307±6051	3315±5365	7130±25,050	38.1±73.6	139±122

PARTICULATE MATTER: The European study (Takai et al., 1998) reported overall average cow-specific emission rates for dairy barns in all four countries of 3.48 g/d·AU inhalable PM and 0.58 g/d·AU respirable PM. There was considerable variation across countries in emission rates for both fractions, which the authors attributed to differences in feeding practices, manure management, bedding materials, and ventilation schemes.

The annual mean $PM_{2.5,}$ PM_{10}, and TSP emissions measured by the NAEMS ranged from 26 to 588 mg/d-hd, 82 to 1225 mg/d-hd, and 405 to 3713 mg/d-hd from confined freestalls compared with 3315, 7130 and 38,050 mg/d-hd in the open freestall barns with dirt exercise lots, respectively (Table 2).

Volatile Organic Compounds: Combining all studies found in the literature prior to the NAEMS yielded a total of 249 individual VOCs identified from air samples taken at or downwind of dairy farms or from one or more materials relevant to dairy operations (manure, silage, rumen gas). Based on 77 target VOC's, the NAEMS observed mean total VOC concentrations ranging from 1261 to 6660 $\mu g/m^3$ at four

dairy farms. The six predominant compounds were n-propanol, ethyl acetate, iso-propanol, n-propyl acetate, acetaldehyde, and methanol.

The current consensus is that producing and feeding silage represents the largest single source of VOCs in dairy operations (Chung et al., 2010). The specific range of VOCs from manure varies with diet, manure age and moisture content (Miller and Varel, 2002). (Filipy et al., 2006) combined in-barn samples (which would have included some silage- and feed-derived VOC) with emission rates of SF_6 tracer, and estimated the emission rate of ethanol alone at 88.7 g/d-hd.

Manure basins, open lots, silage and distributed feed contributed 36, 24, 24 and 14% of a dairy's total VFA emission, based on flux chamber measurements (Alanis et al., 2010). Acetic acid accounted for more than 70% of the emitted VFA. In their study of VOC emissions, Chung et al. (2010) measured average area-specific total VOC emission rates of 0.5 (silage), 0.27 (TMR), 7 x 10^{-4} (flushing lane) 6 x 10^{-4} (open lot) and 3 x 10^{-4} (lagoon) g/h-m^2. Ethanol accounted for about 50% of the silage emissions, and nearly 90% of the TMR emissions.

Based on seven sampling events with two 24-h samples per barn during each event, freestall barns in the NAEMS emitted an average of 34 to 197 g/d-hd of total VOC (Table 2).

MITIGATION TECHNOLOGIES: Ndegwa et al. (2008) reviewed NH_3 emission mitigation techniques for concentrated animal feeding operations. The top methods included reducing N excretion through dietary manipulation, reducing volatile NH_3 in the manure through acidification, and segregating urine from feces to reduce contact between urease and urine.

Scraping to remove manure facilitates NH_3 emission by mixing manure and urine, and spreading the mixture out over a larger surface area. Since flushing does not leave a urine/feces film, it can decrease NH_3 emissions, relative to scraping, by approximately 70% (Kroodsma et al., 1993).

Acidification with mineral acids resulted in significant decreases in NH_3 emission during the full cycle, from storage (~80% reduction) through land application (67% reduction), while increasing the mineral fertilizer equivalent of the applied manure by 43% (Kai et al., 2008).

Perhaps the most widely-explored strategy to reduce NH_3 (and some VOC) emissions is to reduce dietary protein content to just the amount needed for growth/maintenance and lactation, as protein accounts for the bulk of dietary N (Burgos et al., 2007).

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AMMONIA VOLATILIZATION FOLLOWING CATTLE AND PIG SLURRY APPLICATION IN THE FIELD. INITIAL RESULTS OF THE "VOLAT'NH_3" FRENCH PROJECT

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ABSTRACT: Ammonia emissions to the troposphere are becoming a great challenge for French agriculture, due to its economical, environmental and health impacts. Tropospheric ammonia mainly originates from the agricultural sector. Within this sector, livestock is the main emitter, and field emissions are mainly due to volatilization following application of farm yard manure and slurry. Reducing ammonia emissions due to these practices is therefore a major objective of many applied research programs.
In the "VOLAT'NH_3" research project, diffusion samplers are used to measure NH_3 concentration above a field. This paper presents the initial results obtained during the spring 2011 experimental campaign. Four experiments were performed in Western France: three comparing cattle or pig slurry application methods (either applied on the soil surface or incorporated), and one comparing different treatments of pig slurry applied on the soil surface. The kinetics of atmospheric ammonia concentrations measured at 0.3m above each field confirm that (i) emission occurs mainly within a few hours following application, (ii) incorporation is a highly efficient agricultural practice to reduce ammonia volatilization. The results should be used to propose better farming practices and update emission factors in French ammonia emission inventories.

Keywords: ammonia, volatilization, cattle slurry, pig slurry, slurry incorporation

INTRODUCTION: Atmospheric ammonia is becoming a great challenge for French agriculture regarding its economic and environmental impacts. The increasing prices of mineral fertilizers enhance the need for improving the efficiency of organic fertilization, while additionally, air quality regulations are increasingly strengthened. Tropospheric ammonia mainly originates from the agricultural sector. Within this sector, livestock is the main emitter, and field emissions are mainly due to volatilization following application of farm yard manure and slurry (CITEPA 2011). Reducing ammonia emissions due to these practices is therefore a major objective of many applied research programs. Although scientific studies were performed in the past two decades in France (Génermont and Cellier 1997; Morvan, 1999), there remains a lack of field experiments designed to assess the best ways to reduce ammonia emissions following livestock manure application in the field. This situation is merely caused by the lack of a simpler method than those classically available to measure ammonia emissions in the field. Funded by French State CASDAR program, the "VOLAT'NH_3" research project was launched in 2010 with two main purposes:

1) develop a simple method to measure ammonia emissions based on the inverse modelling approach (Loubet et al., 2010) using batch diffusion NH_3 concentration sensors (alpha badges (Sutton et al. 2001); 2) use this method to test the sensitivity to ammonia emissions of various organic (and mineral) fertilizers and the effectiveness of certain agricultural practices to reduce ammonia emissions following fertilization. This paper presents the initial results of the project concerning slurry applications.

1. MATERIAL AND METHODS: Four field experiments (Table 1) were performed in spring 2011: three studying cattle or pig slurry applications, on bare soil surface (BSS) or incorporated after application (IBS; incorporation occurred 0.5 to 2hours after application), and one comparing applications on BSS of pig slurry and digested pig slurry obtained from anaerobic digestion. Plots were statically randomised with 2 replicates per treatment (plots of at least 400m²). Alpha badges were placed at two heights (0.3 and 1m from soil) in each plot and exposed sequentially during 6 periods (6 hours after application, application + 1 day, + 2 days, + 3 days, + 6 days, + 20 days). Other alpha badges were dedicated to background measurement on masts located away from the field and at a height of 3m. Air ammonia concentration evolution during this time was calculated from ammonia quantity trapped in alpha badges using equation (1). Physical and chemical characteristics of the topsoil layer (0-0.25m) were measured before starting the experiments. Soil mineral N content was measured in the 0-0.3m soil layer immediately before slurry application, and after the last alpha badge monitoring. Soil mineral N balance between the beginning and end of experiments was calculated using equation (2) allowing indirect estimation of mineral N losses from slurry application.

Table 1. Main characteristics of experiments carried out during spring 2011.

Experiment	Soil characteristics (0-25 cm)				Treatment	Total N rate* ($kgN.ha^{-1}$)	$N\text{-}NH_4^+$ rate** ($kgN.ha^{-1}$)	$N\text{-}NO_3^-$ rate*** ($kgN.ha^{-1}$)
	Clay ($g.kg^{-1}$)	Silt ($g.kg^{-1}$)	Total C ($g.kg^{-1}$)	pH				
ALL					0 N	0	0	0
Bignan	137	432	17.4	6.4	Pig slurry BSS	148	71	0
					Pig slurry IBS	148	71	0
Derval	184	507	19.9	6.4	Cattle slurry BSS	135	60	0
					Cattle slurry IBS	135	60	0
La Jaillière	189	512	13.7	6.2	Cattle slurry BSS	114	39	0
					Cattle slurry IBS	114	39	0
Trévarez	192	639			Pig slurry BSS	151	106	0
					Digested pig slurry BSS	151	106	0

0N = without N application; BSS: application on bare soil surface; IBS: incorporated on bare soil; *Organic and mineral nitrogen; **NH_4^+ form nitrogen; ***NO_3^- form nitrogen

$$[NH_3] = \frac{QNH_3}{D \times V} \quad (1)$$

$[NH_3]$ = air ammonia concentration during exposure time ($\mu gN\text{-}NH_3\ m^{-3}$); QNH_3 = ammonia quantity trapped in alpha badges ($\mu gN\text{-}NH_3$); D = exposure duration (h); V = alpha badge volume constant ($m^{-3}h^{-1}$).

$$\Delta R = M + X - L - Gx - Ix \quad (2)$$

ΔR = Soil mineral N content variation ($kgN\ ha^{-1}$); M = N mineral from organic matter mineralization ($kgN\ ha^{-1}$); X = Mineral N from slurry ($kgN\ ha^{-1}$); L = $N\text{-}NO_3$ leaching ($kgN\ ha^{-1}$); Gx = N gaseous losses from slurry ($kgN\ ha^{-1}$); Ix = N immobilization in organic matter from slurry ($kgN\ ha^{-1}$).

2. RESULTS AND DISCUSSION: The variability of the NH_3 concentrations between replicates is small, indicating sound accuracy of the method (figure 1). Although work remains to be done to obtain nitrogen fluxes from ammonia concentrations, using the inverse method developed and presented in Loubet et al. (2010 and 2011), the first attempt of calculation seems promising (Loubet et al. 2012). This can also be compared to the great variability of N losses determined using the soil mineral N balance. N losses calculated using soil mineral N balance seem consistent with ammonia concentration kinetics measured in ranking the emissions (figure 2). For example, the highest point in figure 1 concerns the application of pig slurry BSS in Bignan, and is also the treatment with the highest N losses compared with pig slurry IBS in figure 2.The climatic context of spring 2011 in France, with almost no rainfall and warm temperatures during the experiments, was in favour of rapid ammonia emissions: the volatilization occurred mainly during the 2 days following slurry application for the 4 experimental sites. It could also explain the effect of slurry incorporation and slurry anaerobic digestion on ammonia concentrations appearing so strong. These results are consistent with those already published in France and elsewhere.

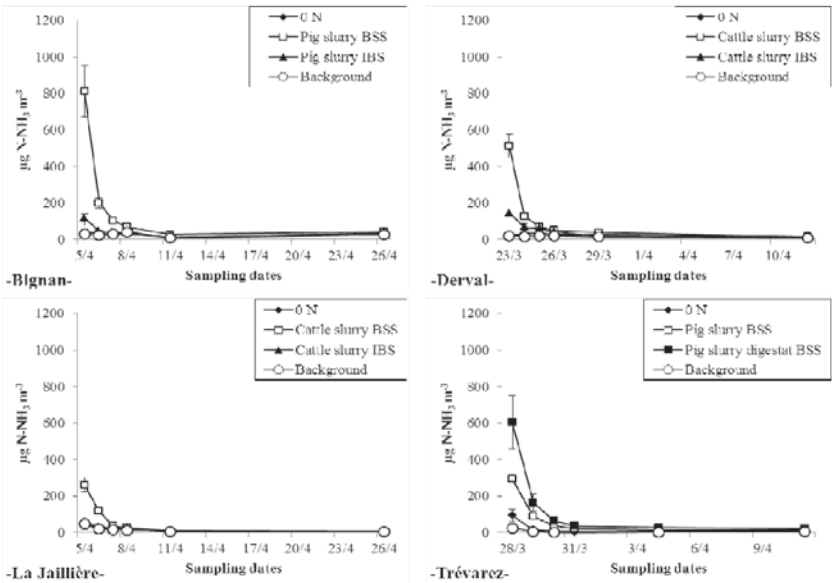

Figure 1. Ammonia concentrations at 0.3m height following slurry applications in 2011 experiments. BSS: application on bare soil surface; IBS: incorporated in bare soil. Vertical bars are standard deviations.

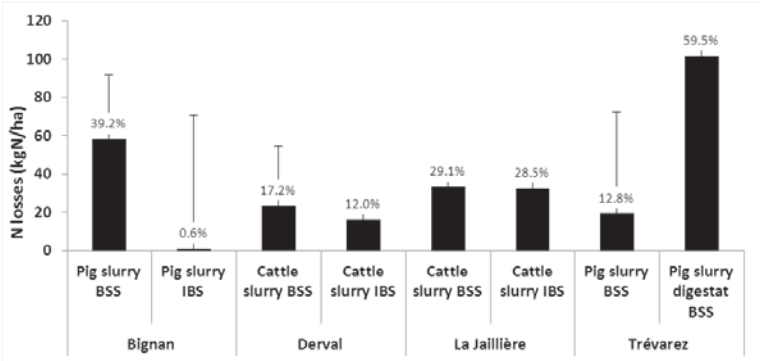

Figure 2. N losses during 2011 experiments estimated by soil mineral N balance. Labels indicate ammonia losses expressed in percentage of total-N applied. Vertical bars indicate the standard deviations.

CONCLUSION: These preliminary results using a new method of ammonia volatilization measurement easy to use in the field are promising. Other experiments will be performed during the spring 2012 experimental campaign with the same protocols. The method should help in developing strategies of ammonia emission reduction after slurry applications in various French agricultural contexts.

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PM_{10} AND GREENHOUSE GASES YEARLY EMISSION FACTORS MEASURED IN FOUR DIFFERENT PIG WEANING ROOMS

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ABSTRACT: Aerial pollutants emitted by intensive livestock production consist mainly of bioaerosols and gases. Bioaerosols are a complex mixture of organic dust, biologically active components and microorganisms that may affect the well-being and the health of humans and animals. The most important greenhouse gases (GHG) generated by animal facilities are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The aim of this study was to quantify the concentration and emission levels of PM_{10} and greenhouse gases emitted from four different mechanically ventilated pig weaning rooms during one year of observation, considering three production cycles per each room. The PM_{10} and GHG measurements were performed in four weaning rooms (R) in three commercial pig houses located in Northern Italy. All rooms had a slatted floor but differed for manure removal system (R1 and R2 were BAT solutions with a vacuum system, R3 and R4 were traditional or reference systems), feeding type and ventilation systems. PM_{10} concentration was continuously monitored by a sampler (HAZ DUST- EPAM 5000) combining "near- forward light scattering" with the traditional gravimetric technique performed to adjust the particulate matter specific gravity of bioaerosol that is typical and specific for every animal house. GHG concentrations were measured every 15 minutes in the exhaust ducts using an infrared photoacustic detector IPD (Brüel & Kjaer, Multi-gas Monitor Type 1302, Multipoint Sampler and Doser Type 1303). CO_2 concentration in the incoming outdoor air was obtained for each room in six independent measurements for each of the three periods during the one year experiment. Emission rate was calculated as the multiplication of pollutant concentration with the ventilation rate recorded in the same minute.
PM_{10} yearly and CO_2 emission rates were mainly affected by high ventilation rate and low humidity. The PM_{10} yearly emission factor ranged from 0.2 (R1) to 2.7 g d^{-1} LU^{-1} (R2), the yearly emission factor for CO_2 ranged from 3556 (R3) to 5997 g d^{-1} LU^{-1} (R1), yearly emission factor for CH_4 ranged from 24.57 (R1) to 77.14 g d^{-1} LU^{-1} in R4; the yearly emission factor for N_2O ranged from 2.29 in R4 to 3.62 g d^{-1} LU^{-1} in R1. The analysis revealed a strong dependence of PM_{10} and GHG concentration on the climate controller and confirmed the variability in the emission inventory of particulate matter and GHG.

Keywords: dust, GHG, emission factor, swine, weaners

INTRODUCTION: There is growing concern regarding the environmental impact of livestock production**.** Aerial pollutants emitted by intensive livestock production consist mainly of bioaerosols and gases. Bioaerosols are a complex mixture of organic dust, biologically active components and microorganisms that may affect the well-being and health of humans and animals. The most important greenhouse gases (GHG) generated by animal facilities are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), Philippe et al.(2007). Carbon dioxide is considerably produced by pig respiration and manure fermentation. However, agriculture is also a CO_2 consumer through plant photosynthesis. This gas' contribution to the greenhouse

effect is less significant than that of CH_4 and N_2O, whose warming potentials are, respectively, 23 and 296 times that of CO_2 (Intergovernmental Panel on Climate Change, IPCC, 2005). Methane is generated from anaerobic bacterial decomposition of organic compounds present in feed and excreta and is emitted both as a by-product of enteric fermentation, a digestive process by which carbohydrates are broken down by micro-organisms in the animal's digestive tract (mainly in ruminants), and from the decomposition of manure under anaerobic conditions, increasing with the Volatile Solids content of the excreta.

Nitrous oxide generation in agricultural systems is a process still not completely understood. N_2O is emitted from manure as an intermediate product of nitrification/denitrification processes under the condition of low oxygen availability, which normally converts ammonia into inert dinitrogen gas; it also contributes to the ozone shield destruction. Nitrous oxide, methane generation and emission in solid manure-based housing systems derive from nitrification/denitrification and degradation of the organic matter processes. All these bioaerosols, the most important aerial pollutants within animal houses, are emitted into the environment by ventilation systems; therefore, these pollutants can also affect the respiratory health of people living near livestock enterprises (IPCC, 2005).

The aim of this study was to quantify the concentration and emission levels of PM_{10} and greenhouse gases emitted from four different mechanically ventilated pig weaning rooms during onr year of observation, considering three production cycles per each room.

1. MATERIAL AND METHODS: Structural and management characteristics of the weaning rooms are reported in Table 1.

1.1. Environmental parameters: The piggeries had ventilation control systems (FANCOM F21) based on a free-running impellers for continuous, real-time monitoring of the ventilation rate. The air exhausts, different in diameter for each room, were equipped with a calibrated ventilation rate sensor. The ventilation rate measurement had a mean error of ± 45 $m^3\ h^{-1}$ (Berckmans et al., 1991). This type of ventilation sensor has 3% accuracy between 200 and 20000 $m^3\ h^{-1}$ and 0-120 Pa pressure difference. The rooms' ventilation control system was equipped to monitor and sample the ventilation rate every minute, internal and external temperature and relative humidity. The number of lodged animals and their weight gain were observed to calculate the emission rate on a livestock unit (LU, 500 kg of live weight) basis. The inside air relative humidity, the rooms' temperature and the temperature in the tunnel under the building, which supplies fresh air to the farrowing and the weaning rooms, were measured by sensors (Fancom). One sensor was placed in the middle of the rooms and the others, to measure external temperature, either in the neighbourhood of the stable, or placed in the tunnel. In the four compartments, continuous measurements were taken for a minimum of 60% of each cycle (20 % at the beginning, 20 % in the middle and 20 % before the end).

Table 1. Structural and management characteristics of the weaning rooms.

		Weaning rooms			
		BAT	BAT	REF	REF
		1	2	3	4
Structural characteristics of the rooms	Ventilation	Perforated ceiling (diffair)	Inlets on the aisle	Inlets on the aisle	Inlets Exhaust ducts in the external wall
	Floor	Slatted PVC	Slatted PVC	Slatted PVC	Slatted PVC
	Manure removal	Vacuum system	Vacuum system	Discontinuous flow with shutter	Discontinuous flow with shutter
	Chimneys	2 7556 and 7780 $m^3 h^{-1}$	2 8896 $m^3 h^{-1}$	2 9000 $m^3 h^{-1}$	2 6500 $m^3 h^{-1}$
	Ventilation rate ($m^3 h^{-1}$)	4057	2867	647	940
Animals	Mean weight at the beginning of the weaning cycle (kg)	7	7	7	7
	Mean weight at the beginning of the cycle (kg)	35	38	35	35
	Duration of the weaning phase	55	65	60	60
	Number of animals	336	320	350	320
	Feeding type	Dry- Wet	Dry (1 phase) and liquid+dry(2 phase)	liquid	liquid

1.2. Dust concentration measuring equipment: PM_{10} concentration was continuously monitored by a sampler (HAZ DUST- EPAM 5000) which combines the traditional gravimetric technique with the "near-forward light scattering" of infrared radiation that enables immediate and continuous measurement of the concentration in mg m^{-3} of airborne dust particles.

The Haz Dust was also used to collect PM_{10} through the traditional gravimetric technique. This procedure was performed to adjust the particulate matter specific gravity of bioaerosol that is typical and specific for every animal house. PM_{10} was collected through the gravimetric method three times within the three periods, at day 15, day 45 and day 70, using polytetrafluoroethylene (PTFE) membranes (47 mm of diameter and 2.0 μm of pore size, SKC). The membranes were weighed using a microbalance (0.000001 g) in a humidity- controlled room before and after dust collection. The filters were dried in a 100°C oven for four hours before weighing. The mean value of dust amount collected on the membranes was utilised as a correction factor to be applied to the continuously collected data. To ensure isokinetic sampling conditions, the dust measuring instrument inside the building was positioned in such a way that the airflow rate, checked with a hot wire anemometer, was generally less than 0.5 m s^{-1}, as described by Haeussermann et al. (2008), while the dust measuring instrument outside the room was placed near the inlet to measure incoming PM_{10}.

1.3. Greenhouse gas concentration measurements: CO_2, CH_4 and N_2O concentrations were continuously measured in the exhaust ducts using an infrared

photoacoustic detector IPD (Brüel & Kjaer, Multi-gas Monitor Type 1302, Multipoint Sampler and Doser Type 1303) collecting data every 15 minutes. The CO_2 concentration in the incoming outdoor air was obtained for each room in six independent measurements (Ni et al., 2000) for each of the three periods during the one year experiment. An overall mean value was applied to the measurements of every room in data processing for carbon dioxide emission. Measurement or monitoring of the pollutant compounds emitted from pig rooms were performed continuously, at least for 60 % of the cycle period, to include all seasons of the year Arogo et al.(2003), (Costa and Guarino, 2009).

Emission rate was calculated as the multiplication of pollutant concentration with the ventilation rate recorded in the same minute:

$$Ei=Ci \times Vi$$

1.4. Statistical analysis: Statistical analysis of the data was performed using SAS statistical software (2008) to evaluate mean values of the emission rate. The effects of the type of manure removal, feeding and ventilation rate on emission rates were investigated (ANOVA).

2. RESULTS AND DISCUSSION: PM_{10} yearly and CO_2 emission rates were mainly affected by high ventilation rate and low humidity. The PM_{10} yearly emission factor ranged from 0.2 (R1) to 2.7 g d^{-1} LU^{-1} (R2), the yearly emission factor for CO_2 ranged from 3556 (R3) to 5997 g d^{-1} LU^{-1} (R1), the yearly emission factor for CH_4 ranged from 24.57 (R1) to 77.14 g d^{-1} LU^{-1} in R4, as reported by Costa[a], (2010). The yearly emission factor for N_2O ranged from 2.29 in R4 to 3.62 g d^{-1} LU^{-1} in R1, as reported by Costa[b], (2010). The trial highlighted a strong effect of ventilation rate on pollutants' emission from the four weaning rooms ($P<0.001$). The two BAT rooms were characterised by high ventilation regimens, while the two traditional rooms by very low ventilation regimens. Dust emission was also linked to an increase in animals' weight over time ($P<0.01$) and to dry feed administration ($P<0.01$), as occurred in the R2.

Table 2. CO_2, CH_4, N_2O, PM_{10} Mean Yearly Emission Factors for the 4 rooms

Room	Mean Yearly Emission Factor g/d LU			
	CO_2	CH_4	N_2O	PM_{10}
R1	5997	24.57	3.62	2
R2	5931	45.9	2.48	2.72
R3	3556	36.76	2.48	0.2
R4	4466	77.14	2.29	0.25

CONCLUSION: Continuous on-line monitoring of dust and environmental parameters can provide accurate measurements of particulate matter emission during the year. The analysis revealed a strong dependence of PM_{10} and GHG concentrations on the climate controller and confirmed the great variability in the emission inventory of particulate matter and GHG.

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AMMONIA EMISSION MEASUREMENTS FROM BEDDED PACK BARNS FOR DAIRY COWS USING A FLUX CHAMBER

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ABSTRACT: There is growing interest among dairy farmers for new housing systems with improved cow welfare. A bedded pack barn is a loose housing system with an enlarged lying area for cows with soft material like compost, sand or dried manure. A research program commissioned by the Dutch Dairy Board and the Ministry of Economic Affairs, Agriculture and Innovation was established to study welfare implications and environmental effects of this housing system under Dutch circumstances. In this paper the initial results of the environmental effects are presented. The objective was to measure ammonia emissions from different bedding materials under practical circumstances. The three bedding materials were sand (A), sawdust (B) and a mixture of peat/clay soil and reed called 'Toemaak' (C). Measurements occurred between April 2009 and May 2010. Area available for bedding A, B and C was 14.5, 14.6 and 16.6 m^2 per cow, respectively. All bedding was measured at 4-5 different moments and per moment on 3-4 different spots. Ammonia emission was 415, 227 and 183 mg NH_3 per m^2 per hour for bedding A, B and C, respectively. Calculated per cow and related to an assumed emission of 1,200 mg NH_3 per m^2 per hour for a common housing system with concrete slatted floor, the ammonia emission per cow was 192, 107 and 111%, respectively (cubicle system=100%). It was concluded that although emission levels per m^2 were significantly lower compared to traditional loose housing systems, the emission per cow is higher due to the larger emitting area cow. In further research the emission of nitrous oxide should also be included.

Keywords: dairy cattle, ammonia emission, loose housing system

INTRODUCTION: There is growing interest among dairy farmers for new housing systems with improved cow welfare and less environmental impact. Currently, dominant loose housing systems have concrete walking areas and cubicles with mattresses or litter as lying area. Total available space ranges from 3 to around 6 m^2 per cow. Several analyses show that more space per cow and softer walking and lying areas will reduce the most urgent health and welfare problems in dairy cattle housing (Somers et al., 2003). A bedded pack barn is a loose housing system with an enlarged lying area for cows with soft material like compost, sand or dried manure. It has already been in use for several years in the USA (Barberg et al., 2007), using saw dust that compost together with the manure, and in Israel where dried manure is used as bedding. A research program commissioned by the Dutch Dairy Board and the Ministry of Economic Affairs, Agriculture and Innovation was established to study welfare implications and environmental effects of this housing system under Dutch circumstances. The first phase contained model calculations and lab experiments (Dooren et al., 2010), the second phase experiments the use of three different bedding materials under practical circumstances (Dooren et al., 2012). In this paper, the results are presented of the second phase, which concerns ammonia emissions. The objective was to measure ammonia emissions from the bedding using an open flux chamber.

1. MATERIAL AND METHODS:

1.1. Bedding materials: The measurements were conducted on three research farms of Wageningen UR Livestock Research: Aver Heino in Heino for sand bedding, Waiboerhoeve in Lelystad for compost bedding and Praktijkcentrum Zegveld in Zegveld for a mixture of peat/clay soil and reed ('Toemaak'). The sand bedding consisted of a 20 cm top layer of sand (M3C) on a 15 cm layer of lavaliet. Faeces was manually removed from the bedding three times a day. Urine was drained through the bedding. The total bedding area was 170 m^2 (14.5 $m^2 \cdot cow^{-1}$). The compost bedding initially consisted of a 50 cm layer of coarse sawdust. By cultivation, faeces and urine were mixed with the first 20 cm daily and with the entire layer weekly. The total bedding area was 234 m^2 (14.6 $m^2 \cdot cow^{-1}$). Sawdust was added around every 6 weeks. The 'Toemaak' bedding consisted of a mixture of peat/clay soil, dredged from ditches and canals, and reed in a layer of around 70cm. The total bedding area was 169m^2 (14.1 $m^2 \cdot cow^{-1}$). On a daily basis the bedding was cultivated and extra reed was added.

1.2. Ammonia emission, ventilation rate, temperature and relative humidity: The ammonia emission was measured using an open flux chamber (2.37 m x 2.32 m x 0.40 m) (Mosquera et al., 2010). The ammonia flux Q ($mg \cdot h^{-1} \cdot m^{-2}$) from the emitting surface A (5.50m^2) was calculated by multiplying the ventilation rate Φ ($m^3 \cdot h^{-1}$) and the difference in concentration between the incoming (C_{in}) and outgoing (C_{out}) from the flux chamber in $mg \cdot m^{-3}$:

$$Q = \frac{\Phi(C_{out} - C_{in})}{A}$$

The ammonia concentration in the incoming and outgoing air was measured using two photo acoustic monitors (Innova 1312). A fan (Fancom FMS35) with a 35 cm diameter and a maximum ventilation capacity of 3000 $m^3 \cdot h^{-1}$ was installed in the outgoing tube. The ventilation control unit (Fancom FCTA) was set at 23% of maximum capacity, resulting in a targeted airspeed across the bedding surface of 0.2 $m \cdot s^{-1}$. Ventilation rate was measured using a calibrated fan wheel anemometer. Air temperature and relative humidity close to flux chambers were measured using a Rotronic Hygromer®. This sensor had an accuracy of ± 1.0 °C and ± 2 % for temperature and relative humidity, respectively. Average temperature, relative humidity and ventilation rate were recorded every 5 minutes by a data acquisition system (Campbell Scientific Inc.). Measurements were performed on 4-5 days at 3-4 spots every day between April and November 2009 for the sand and compost bedding and between October 2009 and May 2010 for the 'Toemaak' bedding. Samples of bedding material were taken, every measurement analysed on Dry Matter, Organic Matter, Total N, Total P and Total K. Temperature of the compost bedding was measured regularly at different depths.

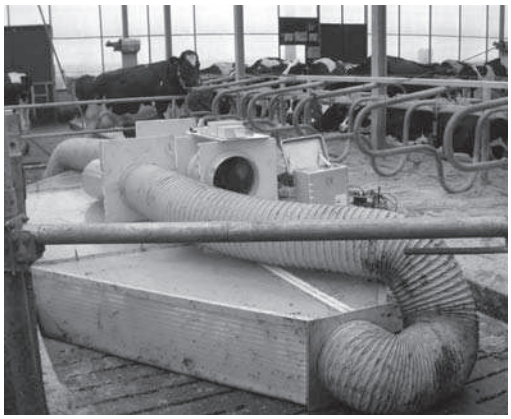

Figure 1. Open flux chamber.

2. RESULTS AND DISCUSSION: Main results are presented in Table 1. T-test proved differences between ammonia emission per hour per m^2 of sand and compost and of sand and 'toemaak' as significant ($p<0,01$). Assuming cows in bedded pack barns also have access to $2m^2$ slatted flooring and cows in cubicle barns have access to $4m^2$ slatted flooring, and with an ammonia emission per $h^{-1} \cdot m^{-2}$ from a slatted floor with slurry pits of around 1200 $mg \cdot h^{-1} \cdot m^{-2}$, the ammonia emission per cow per year is 192%, 107% and 111% of the emission from a cubicle barn for sand, compost and 'toemaak', respectively.

Table 1. Mean values (± SD) of measurements.

	Bedding material		
	Sand	Compost	Toemaak
Air temperature (^oC)	18.7±5.8	17.8±4.2	14.3±9.6
Relative Humidity (%)	62.5±16.4	63.7±20.6	60.2±19.7
Ventilation rate ($m^3\ h^{-1}$)	809±24	774±73	740±80
Ammonia emission ($mg \cdot h^{-1} \cdot m^{-2}$)	415±78	227±67	183±96

Despite the faeces removal, the sand bedding became progressively contaminated with organic matter resulting in increasing total nitrogen content of the top layer (Figure 2). Increasing total nitrogen content of the compost bedding was expected as faeces and urine were mixed daily. Temperature of the compost bedding rose gradually during the experiment until a maximum of 44^oC, indicating that actual composting processes took place. This can result in nitrogen losses other than ammonia, such as nitrous oxide, which is an important greenhouse gas but was not measured.

Mixing of reed and the peat/clay soil proved difficult. Despite the high nitrogen content of the 'toemaak', the ammonia emission was relatively low compared to sand and compost. The clay possibly bound part of the nitrogen.

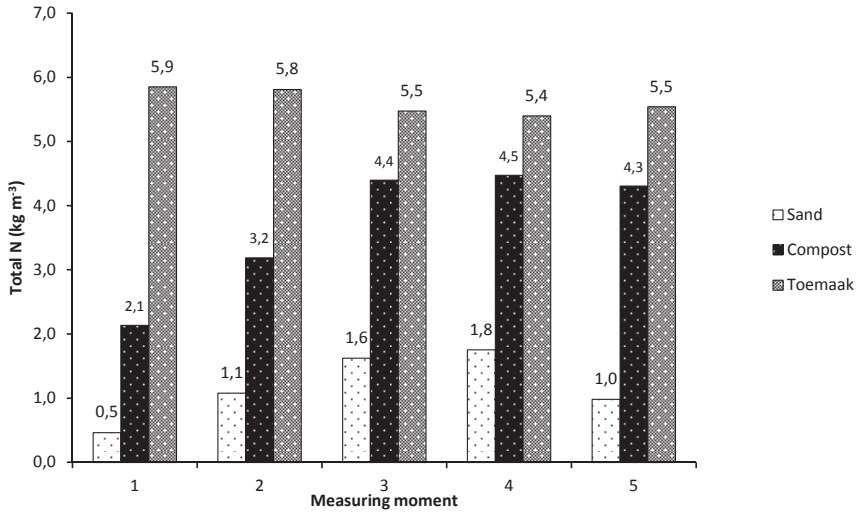

Figure 2. Total Nitrogen content of different bedding material at different measuring moments.

CONCLUSION: It was concluded that although emission levels per m^2 were significantly lower compared to traditional cubicle housing systems, the emission per cow is higher due to the larger emitting area. In further research the emission of nitrous oxide should also be included, especially for compost bedding.

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ESTIMATION TEST OF GASEOUS EMISSIONS FROM FISHPONDS WITH CONTRASTED INPUTS

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ABSTRACT: Daily operations in fishponds induce gas emissions, mainly of carbon dioxide (CO_2), oxygen (O_2), ammonia (NH_3), methane (CH_4), nitrous oxide (N_2O) and nitrogen (N_2). Estimating the effect of management practices on ammonia and greenhouse gas emissions is a new challenge for the sustainable development of fish farming and increased productivity of fishponds. Experiments were performed on eight fishponds at the aquaculture experimental platform of the University of Dschang, Cameroon. Gases were collected using a small static chamber floating on the pond surface for 24 hours. Results show that CO_2 gradients related to fish densities in the fishponds and to organic inputs. CH_4 emissions measured in the ponds related to higher oxygen levels in the water due to higher photosynthesis and a large deposit of dead plankton on the bottom. NH_3 and N_2O gradients were significantly correlated, while no correlation was detected between NH_3 and CO_2. It is assumed that higher N input (urea) or higher fish population (higher N excretion) induced higher NH_3 emissions and higher N turn-over, inducing limited N_2O emissions and nitrite accumulation below toxic levels. Further work in controlled conditions could provide more reliable emission measurements and confirm the observed trends.

Keywords: fishponds, Cameroon, nitrous oxide, methane, ammonia

INTRODUCTION: The phenomenon of global warming due to greenhouse gas emissions is not only related to the consumption of fossil fuels due to heavy industrialization, but also to human activities (Dobrescu, 2009). Animal farming, as a human activity, emits greenhouse gases that accumulate because of increasing food demand. Some methods for estimating them, especially on livestock farms, have been developed and implemented in a variety of contexts (Hobson et al., 2005; Loyon et al., 2007; Hassouna et al., 2010). Few of these studies have focused on fish farms, which can emit gases. In semi-intensive aquaculture in ponds, these gases come from fish metabolism, mineralization of fecal wastes, organic manures, and photosynthetic activity (because fish feeding is mainly based on natural productivity of the aquatic system). Most gases are carbon dioxide (CO_2) from respiration, oxygen (O_2) from photosynthetic activity, ammonia (NH_3) from fish excreta resulting from protein digestion, and methane (CH_4) and nitrous oxide (N_2O) from incomplete mineralization of organic matter. Their amounts are related to the biotransformation processes within the ponds (Efole Ewoukem et al., 2012). Development of a method to estimate gaseous emissions targets not only the assessment of fish farms' contribution to global warming or acidification, but also helps to implement sustainable models of fish farms.

1. MATERIAL AND METHODS: The study was conducted in 2010 at the aquaculture experimental platform of the Application and Research farm of the University of Dschang, Cameroon, with an average altitude of 1400 m. The climate is

tropical humid modified by altitude. Mean temperature ranges from 18-27°C and relative humidity ranges from 47-90%.

Eight 25-m^2 ponds with different species compositions and trophic levels were used for the experiment. The bottoms of ponds were covered with PVC liner. Trophic and species compositions are summarized in Table 1.

Air was collected continuously during 24 hours from random locations on pond surfaces and from the surrounding environment in 5- or 10-l Theldar bags (SKC sample bag 232) using a floating chamber. The chamber was made of 0.5 x 0.5 x 0.3 m PVC plates covered on one side to form a chamber. Floats were attached on the sides. A battery-powered aquarium pump (pump BK) was linked to the chamber to fill the bag via a flexible tube equipped with a microfilter.

Table 1: Trophic and species composition of fish ponds sampled. Tilapia = Oreochromis niloticus, catfish1 = Clarias gariepinus, catfish2 = Clarias jaensis, Carp = Cyprinus carpio, Chla = Chlorophyl a.

Ponds	Fish association	Fish density (Ind/m²)	Mineral enrichment	Fertilizer and feed	Chla (mg/m^3)	Fish Biomass gain (g)
1	Tilapia + Catfish 1	1.2	none	chck. manure	2,7	1938
2	Tilapia + Catfish1+2	1.4	wood ash	chck. manure + urea+ bread	8,3	1955
3	Tilapia + Catfish 1	1.2	lime + wood ash	chck. manure + bread+ wheatbran	6	2046
4	Tilapia + Catfish1 + Carp	1.4	none	chck. manure + urea+ bread+ wheatbran	25,8	2771
5	Tilapia + Catfish1 + Carp	1.4	lime + wood ash	chck. manure + urea	2,1	2157
6	Tilapia + Catfish 1	2.2	Lime	chck. manure + urea+ bread	0,5	4332
7	Tilapia + Catfish1+2	1.4	lime	chck. manure + urea+ wheatbran	2,6	3890
8	Tilapia + Catfish1+2 + Carp	1.6	wood ash	chck. manure + wheatbran	4,3	2859

Gas analysis was performed using a photoacoustic gas analyzer (INNOVA 1412). Concentration gradients were calculated and interpreted on the basis of the mass balance of the system (Hassouna et al., 2010). Gas emissions were calculated as the difference between gas concentrations collected in the ponds and those of the ambient air in the surrounding environment. A gas gradient was retained when its absolute value was greater than the standard deviation of the mean concentrations.

2. RESULTS: The concentration gradients of gas samples and their ratios are summarized in Table 2. The net positive CO_2 gradient shown in the table indicates that the air collected from the chamber-concentrated pond emissions was not contaminated by outside air.

Table 2: Gas concentration gradients and their ratios.

	Gas gradients (mg/m^3)				Ratios of gas gradients			
Pond	CO_2	CH_4	NH_3	N_2O	NH_3/N_2O	NH_3/CH_4	CO_2/CH_4	CO_2/NH_3
1	586.7	0.8	0.2	0.2	1.3	0.27	698	2541
2	789.4	-2.1	0.2	0.3	0.9	-0.11	-367	3338
3	920.9	0.9	0.3	0.4	0.9	0.37	1007	2742
4	870.9	-1.1	0.4	1.3	0.3	-0.41	-810	1991
5	482.3	nd	0.2	0.2	1.5	Nd	nd	2097
6	7104.9	-1.5	0.5	1.2	0.4	-0.31	-4805	15530
7	920.9	-0.7	0.4	0.7	0.6	Nd	0.0	nd
8	620.0	nd	0.2	0.3	0.9	Nd	0.0	nd

Generally, CO_2 emissions observed in 2010 were much higher than previous samples in 2009 (30-80 mg/m^3). This high level is explained by a better rearing temperature for the fish associated with high microbial activity in the bottom in 2010. A positive gradient indicates higher CH_4 emissions in ponds 1 and 3, which had a low fish density (1.2 ind/m²), with a CO_2/CH_4 ratios of 700-1000, indicating low CH_4 emissions compared to those of CO_2. In contrast, negative gradients indicate lower CH_4 in ponds 2, 4, 6 and 7 having higher fish densities (1.4, 1.4, 2.2 and 1.4 ind/m², respectively) and using lime or ash for mineral enrichment. These CH_4 fluxes remain low compared to those of CO_2.

The observation of CH_4 consumption in these semi-intensive systems could be related to O_2 abundance in the middle and bottom of the ponds due to high algal development, responsible for activation of organic matter mineralization of bottom-soil micro-organisms (Loir and Mollo, 2008). CO_2 emissions seem independent from NH_3 and N_2O emissions, as no correlation was observed. Ponds had a stable gradient of NH_3, and some had an increase in the N_2O gradient. Higher emissions of gaseous N compounds were observed when urea and wheat bran were associated with pond supplementation or with high fish density.

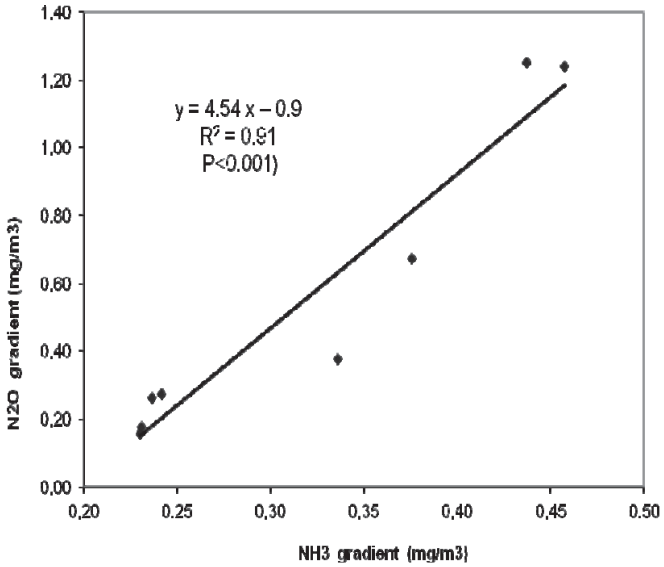

Figure 1: Correlation between NH_3 and N_2O emission gradients of tropical polyculture ponds with different levels of inputs, fertilizers and fish densities.

This result reveals that more nitrogen inputs per unit area leads to more recycling but relatively stable concentrations of NH_3 in water and gas emissions. This is confirmed by the strong positive correlation between NH_3 and N_2O gradients (Fig. 1).

Additionally, more nitrogen input into the system would lead to the production of more dissolved NH_3 (mineralization and excretion) and thus a higher NH_3 gradient. In this case, NH_3 does not accumulate because it is processed more intensively in the pond food chain, hence the increased N_2O gradient (due to nitrification and denitrification). This transformation could induce high concentrations of nitrites toxic to fish, but the high fish productivity indicates that nitrite quantities are below the toxic limit. The increase in nitrogen transformation is a consequence of its assimilation in the trophic chain, which supports the assembling of polycultures to optimize available resources (Verdegem, 2007; Rahman et al., 2008; Verdegem and Bosma, 2009; Efole Ewoukem, 2011) and build sustainable fish farming.

CONCLUSION: Pond management had a clear influence on daily emissions of CO_2, CH_4, NH_3, and N_2O. The CO_2 gradient increased with fish density. The NH_3 and N_2O gradients were correlated, and both increased with nitrogen inputs. A high CO_2/NH_3 ratio indicated a reduction in NH_3 emissions whenever nitrogen-based feeds are used. Lower nitrogen losses were assumed to result from higher nitrogen recycling. The CH_4 sink has been hypothesized to be linked to photosynthetic activity producing O_2 in the water. Pond management can both improve feed efficiency of fish production and reduce NH_3, N_2O and CH_4 emissions.

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N_2O, CH_4 AND CO_2 EMISSIONS FOLLOWING SOIL APPLICATION OF DUCK AND PIG SLURRY PARTICLE SIZE FRACTIONS

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ABSTRACT: Solid-liquid separation of slurry has been promoted to improve slurry management. The aim of the present work was to assess the influence of slurry particle size on the N_2O, CO_2 and CH_4 emissions following soil incorporation. A laboratory experiment was performed to measure the N_2O, CO_2 and CH_4 emissions following incorporation into an agricultural sandy loam soil (Dystric Cambisol) of 8 particle size fractions(>2000 µm, 2000-500 µm, 500-100 µm, <100 m), obtained through laboratorial separation from pig and duck slurry.

The highest values of cumulated N_2O emissions were observed from the >2000 µm fraction but the slurry particle size had little impact on N_2O emissions. CH_4 emissions were short-term (3 days) and were detected only in treatments amended with the grossest fractions. During incubation, 32.5% to 74.4% of the applied C in pig slurry and between 21.3% and 41.9% in duck slurry was lost as CO_2. Lower CO_2 emissions were observed in treatments amended with duck slurry fractions relative to duck WS (whole slurry) application, but higher CO_2 emissions were observed from the >2000 µm pig fraction relative to WS.

Mechanical separation of slurry into fractions and targeted application of specific fractions on soil appears a potential suitable management tool to reduce GHG emissions.

Keywords: GHG, C and N dynamics; pig and duck slurry treatment, particle size fractionation

INTRODUCTION: Recycling animal slurry on-farm through soil application is an efficient and sustainable practice in livestock production. However, the available agricultural area is often insufficient to recycle all slurry produced in large and intensive units, and it is well-known that slurry application on soil increases CO_2, N_2O and CH_4 emissions.

Slurry separation into a liquid (LF) and a solid (SF) fraction appears an acceptable solution in slurry management since it enables SF exportation to other farms at a lower cost than slurry. Nevertheless, previous work (Fangueiro et al., 2008, 2012) showed that slurry separation may increase emissions of some GHG after soil amendment and that the slurry particle size may affect the extent of these emissions. However, most of these cited works were performed only with cattle slurry, albeit swine and poultry slurry production are also significant, mostly in emerging Asian countries.

The present study aims at examining the influence of pig and duck slurry particle size on N_2O, CO_2 and CH_4 emissions following soil incorporation.

1. MATERIAL AND METHODS: The pig and duck slurry was obtained from commercial farms located near Lisbon (Portugal). Four particle size fractions

(>2000 µm, 2000-500 µm, 500-100 µm, <100 µm) of each slurry were obtained by manual sieving. The whole slurries (WS) and particle size fractions were then analyzed, as described in Fangueiro et al. (2012). The main parameters are shown in Table 1.

The experimental procedure used to follow CO_2, N_2O and CH_4 emissions from soil amended with WS, or the slurry fractions previously referred, is fully described in Fangueiro et al. (2012). A sandy-loam soil (600 g of dry soil) was amended at a rate of 130 mg total N kg^{-1} dry soil with the different materials and then moistened to reach 60% water-filled pore space. Amended soils were then aerobically incubated for 50 days at 25ºC. Gas fluxes were measured regularly using a trace gas analyser (TGA) (1412 Photoacoustic Field Gas-Monitor, Innova Air-Tech Instruments) (Pereira et al., 2010).

The experiment included 11 treatments, including a control (CON) replicated four times. The least significant different (LSD) tests, based on a t-test at a 0.05 probability level, were used to statistically compare means. Statistical differences referred to in the text as significant correspond to $P < 0.05$, unless otherwise stated. The statistical software package used was STATISTIX 7.0 (Analytical Software, Tallahassee, USA).

Table 1. Main Characteristics of the whole slurry and fractions used in the present work (N=3).

Slurry Fraction	Dry matter (g kg^{-1})	Total N (g kg^{-1})	Organic C (g kg^{-1})	C:N ratio
Pig - Whole slurry	162.3	28.9	362.1	2.23
Pig - >2000 µm	74.7	147.4	439.7	5.89
Pig - 2000-500 µm	60.2	111.8	477	7.92
Pig - 500-100 µm	70.8	102.1	432.2	6.10
Pig - <100 µm	205.4	25.6	339.9	1.65
Duck – Whole slurry	160.2	17.8	356.1	2.22
Duck - >2000 µm	83.2	113.4	425.5	5.11
Duck - 2000-500 µm	110.0	113.0	448.9	4.08
Duck - 500-100 µm	108.1	112.1	393.1	3.64
Duck - <100 µm	192.2	13.2	364.5	1.90

2. RESULTS AND DISCUSSION: The (<100 µm) fractions in both pig and duck slurry represent more than 95% in mass of the WS. Consequently, the WS and the (<100 µm) fraction (pig and duck) have a similar composition in terms of total N and C concentrations. The other 3 fractions of duck slurry have similar compositions, whereas in the case of pig slurry, a slight variation was observed between these fractions. More information on the composition and properties of slurry particle size fractions can be found in Fangueiro et al. (2010).

N_2O emissions were observed in all treatments during the entire experiment, even at a low rate (Figure 1). Furthermore, only the grossest fractions (> 2000 µm and 500-2000 µm) in both slurries, as well as the Duck-WS, led to N_2O emissions significantly higher than the Con treatment. Nevertheless, our results show that particle size has a slight effect on N_2O emissions.

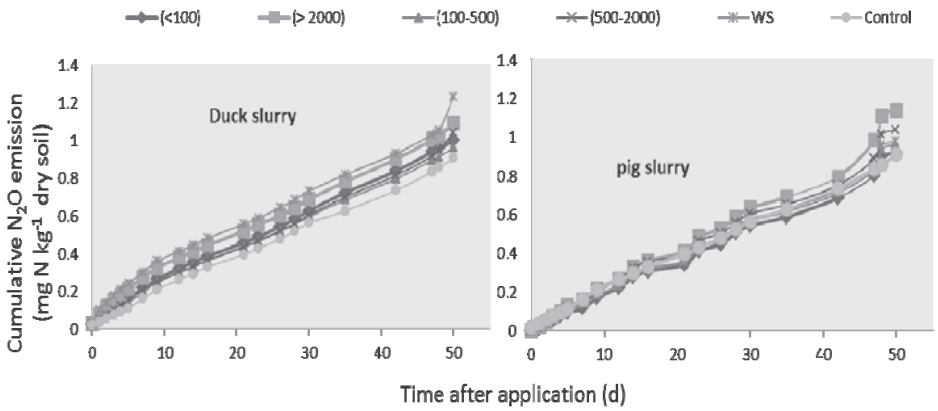

Figure 1. Average of cumulative N_2O emissions after incorporation of different slurry fractions into soil (N= 4).

Methane emissions were short-term (3days) and detected only in fractions > 500 µm WS in the case of pig slurry, whereas methane oxidation was observed in treatments with duck slurry fraction, as well as Duck-WS on day 1. In both cases, the amount of C released or fixed by the soil as CH_4 was negligible (< 0.3 mg CH_4-C kg^{-1} dry soil).

Table 2. Rates of CH_4 (µg CH_4-C kg^{-1} dry soil d^{-1}) after incorporation of different slurry fractions into soil and cumulative amounts of CH_4 exchange after 3 d (N = 4).

Slurry Fraction	Day 0	Day 1	Day 2	Day 3	Cumulative
Pig - Whole slurry	62.34	41.11	*8.83*	*11.24*	149.07
Pig - >2000 µm	97.50	55.71	44.63	18.69	255.93
Pig - 2000-500 µm	73.87	27.89	*7.99*	*-8.49*	142.43
Pig - 500-100 µm	**43.65*	*47.33*	*10.68*	*-15.86*	*115.55*
Pig - <100 µm	*12.16*	*1.89*	*-34.38*	*-39.12*	*-33.81*
Duck – Whole slurry	-34.13	-81.83	*25.10*	43.64	-86.10
Duck - >2000 µm	*36.03*	-40.82	40.12	35.01	*70.86*
Duck - 2000-500 µm	*-21.26*	-52.15	43.51	20.45	*-30.31*
Duck - 500-100 µm	*-25.26*	-45.77	*3.72*	24.01	*-67.93*
Duck - <100 µm	*-17.73*	-43.87	*10.70*	19.68	*-49.92*

**Values in Italics are not statistically different from 0*

Nearly 40% of the applied C was released as CO_2 during the first 10 days of incubation in WS and (<100 µm) duck slurry, whereas in all other fractions, losses of C as CO_2 occurred slowly and did not exceed 30% of the applied C. In the case of pig slurry, all fractions and WS followed similar trends in terms of CO_2 emissions, except the (100-500 µm) fraction, which led to lowest CO_2 emissions. It is to refer that more than 70% of the applied C was lost as CO_2 from the >2000 µm pig slurry fraction. No relationship was established between the slurry particle size and CO_2 emissions, even when it appears that the finest duck slurry fractions and the grossest pig slurry fractions led to higher emissions than the respective WS or other isolated fractions.

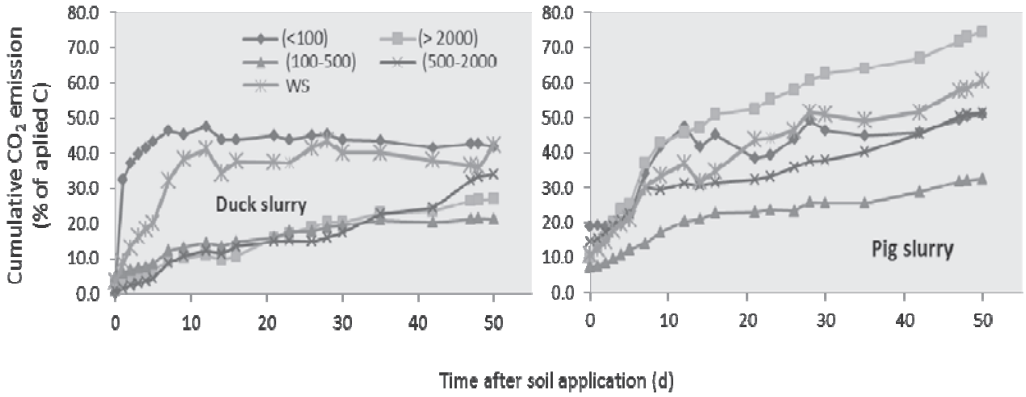

Figure 2. Average of cumulative CO_2 emissions after incorporation of different slurry fractions into soil (percentage of applied C) (N= 4).

CONCLUSION: Slurry particle size had a poor effect on N_2O and CH_4 emissions from amended soil concerning pig and duck slurries, both presenting a low dry matter content. Nevertheless, this parameter had a stronger effect on the CO_2 emissions with opposite effects observed in duck and pig slurry. Solid/liquid separation of these slurries should, therefore, have no impact on N_2O and CH_4 emissions following soil application. However, targeted application of specific fractions into the soil must be promoted to limit CO_2 emissions.

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GREENHOUSE GASES AND AMMONIA EMISSIONS ASSESSMENT FROM DAIRY HOUSING BY MEANS OF A SIMPLIFIED METHOD

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ABSTRACT: IPCC proposes emission factors based on categories of livestock and manure management system typology to estimate GHG emissions from dairy buildings. Throughout the French dairy livestock sector, as in Lorraine, straw is frequently used for bedding and solid manure is the most significant form of manure. This is the case in mixed crop-livestock organic farms considered in our experiment, in comparison to a grassland livestock system. The mixed crop-dairy system (MS) herd is housed from November to April in loose housing with a deep straw litter, leaving a concrete floor that is cleaned twice a day by scraping. The grassland system (GS) dairy herd is housed from December to March in cubicles and passageways, which are also scraped twice a day. Buildings are both naturally ventilated.
A simplified methodology was applied to assess indoor emissions by using the air content ratio method developed from indoor and outdoor gas content measures. CH_4, CO_2, N_2O and NH_3 contents were established with use of an infrared photo-acoustic analyser. Sampling occurred during two full winter periods.
The calculated emission values are smaller than those previously reported, but they agree with others obtained in France, even when i) they are strongly lower for nitrogen emissions (N_2O and NH_3) and ii) GS seems low in emissions. The deep straw litter of MS contributes to dramatically increased emissions of all gases, although the feeding level and the forage quality of GS are lower and probably result in increased CH_4 cow emissions.

Keywords: GHG, NH_3, dairy housing, simplified method, organic livestock farming

INTRODUCTION: In a given area, greenhouse gas emissions from livestock buildings, such as methane, nitrous oxide and carbon dioxide, and ammonia volatilization differ according to animal category and type of housing. Beyond cows' characteristics and feeding factors, emissions depend on the manure management system and greatly contribute to climate change and air pollution. These emissions appear as N and C (or energy) losses, especially at high levels. Regarding organic livestock farming, we seek to estimate these losses and, when relevant, to consider such livestock farming as a mitigation option for climate change. At the same time, it could encourage the livestock systems to become more economical through increased self-sufficiency.

1. MATERIAL AND METHODS: The experimental system (Coquil et al., 2009) consists of two dairy herds located in the INRA Unit of Mirecourt (Eastern France). These herds were managed according to organic standards since 2004. A grassland system (GS) dairy herd (37 cows calving from January to April) was housed from December to March in cubicles equipped with rubber mats and a little straw (0.2 Kg/LU/day). Cows were exclusively fed hay from permanent pasture during the housed period (without concentrate). Passageways were scraped twice a day and the manure removed as slurry to an open-top tank. The other herd (60 cows calving from August to November) was included in a mixed crop-dairy system (MS). This herd was

housed from November to April in loose housing with a deep straw litter accumulated for six weeks (8.7 Kg/LU/day). The area where the animals stand to feed was also scraped twice a day, with the refuse placed in storage near the barn. The cows were fed hay from permanent grasslands and leys (including alfalfa, clover and some grasses), and unlike GS, a small amount of cereal (2.7 KgDM/day). Both buildings were naturally ventilated.

For estimating gas emissions, Paillat et al. (2005) proposed a mass balance approach at the building level and the calculation of the ratio between inside and outside gas contents. It enables avoiding calculation of the air flow, which is difficult to obtain in the naturally ventilated cattle buildings. The method relies on considering gas emissions as losses calculated from the balance between housing inputs (fodder, feeds and straw) and outputs (animal production s.l. and manure). These losses consist of CO_2 and CH_4 for carbon, and N_2O and NH_3 for nitrogen, neglecting N_2 emissions. Carbon losses were established according a carbon balance calculated at the animal level, as Faverdin et al. (2007) suggested, including the use of straw for bedding. Fodder, feeds, straw, milk and manure were weighed, sampled and analysed. This simplified method was applied by Brachet (2007) in different French conditions, and was then presented by Dollé (2009).

Calculation of C losses is necessary to estimate the CO_2 emissions and then calculate the emissions of CH_4, N_20 and NH_3 according to the following equations:

C Losses = (C ingested + C straw – C milk – C pregnancy – C manure)

EC- CO_2=C Losses/(1 + (gradientC- CH_4/gradientC- CO_2))

EC- CH_4=EC- CO_2*(gradientC- CH_4/gradientC- CO_2)

EN-N_20=EC-CO_2*(gradientN-N_20/gradientC-CO_2),EN-NH_3=EC-CO_2*(gradientN-NH_3/gradientC- CO_2)

To obtain gas contents at a given time, two samples of outside and inside air of the barn were taken with simple equipment: an electric air pump connected to 10L Tedlar® sampling bags through flexible Tygon® tubes for approximately 10 to 15 min. The samples were analysed during the following hours by using an infrared photo-acoustic analyser INNOVA®1412 to obtain at least 20 content values from each sample. Air sampling was performed 7 times a day, each fortnight in early 2010, late 2010 and early 2011 when the herds were fully housed. In regard to certain conditions (outside gas contents and enthalpy higher than inside ones, no silage distribution), 13 daily periods were used to estimate CH_4, CO_2 and NH_3 emissions, but only 10 days for NO2 from the measured 18. Climate characteristics were measured outside and inside the barns (air temperature, air relative moisture). The outdoor mean temperature of calculation periods ranged from -5.6°C/+12.8°C, and weather conditions were diverse.

2. RESULTS AND DISCUSSION: Sampling occurred 7 times a day each fortnight. To obtain daily averaged gas contents for outside and inside conditions, we weighed the 7 instantaneous values with representative durations of 3, 5 or 7 hours, according to the samples.

At the beginning of the winter period (December), most of the cows in the GS dairy herd were dried. As the calving period started in mid-January, the herd included more lactating cows during the entire measurement period. At the same time, the number of heifers and dried cows decreased up to the last sampling date. Therefore, the average live weight of these cows reached 718 Kg, and they yielded 5310 Kg of fat-corrected milk during 276 lactation days. The feeding level of the GS cows averaged 2.17 KgDM ingested/KgLW, while the fodder quality was rather low through an organic matter digestibility of only 61%. Considering the type of housing (cubicles and slurry), the expected amount of effluent (DEPSE, 2001) was 60 L / LU a day, while we weighed 71.5 ± 7.6 Kg / LU.

During the entire measurement period, the MS herd included only lactating cows. On average, 48% of these cows were pregnant (13 weeks long). Their average live weight was 679 Kg and they yielded 5851 Kg of fat-corrected milk during 300 lactation days. The feeding level of the MS cows averaged 3.03 KgDM ingested/KgLW and the ration showed better quality through an organic matter digestibility of 70%. According to the typology of French cattle housing, from this type of barn (deep litter and farm yard manure), the expected amount of liquid manure produced on the scraped area (DEPSE, 2001) was expected to be 34 Kg / LU a day, while we weighed 43 ± 4 Kg / LU. The mean deep litter age was 28 days.

Table 1. Daily gas emissions from the dairy buildings in Mirecourt Unit, for grassland and mixed crop livestock systems during two wintering periods (2009-10 and 2010-11).

g / LU / day	C- CO_2	C- CH_4	N-N_20	N- NH_3
MS Mirecourt	8496 ± 233	804 ± 42	1.40 ± 0.30	19.18 ± 2.37
Brachet (2007)	9271	828	2.2	48
GS Mirecourt	2260 ± 178	237 ± 17	0.41 ± 0.05	3.70 ± 0.41
Brachet (2007)	3715	382	2.9	50

Considering the 13 measurement dates well-describing a full winter period through their diversity, we simply estimated winter emissions by means of an arithmetical average of the 13 daily values of gas emissions for CH_4, CO_2 and NH_3, while only 10 daily values provided emissions for N_20. We compared these results (Table 1) with those obtained by Brachet (2007) in 19 dairy buildings in summer of 2007. Only four included deep litter with a permanent attendance of cows, but they appear in agreement with MS-Mirecourt results, except for NH_3 emissions. The other buildings measured by Brachet were diverse (tied stalls, cubicles and deep litter removed) with a reduced attendance of cows (during the night or only during milking time). These last results showed higher values than in GS-Mirecourt, but lower than those of deep litter housing, especially for CO_2 and CH_4 emissions.

Most significant is the difference between our two housing systems: MS deep litter system with scraped passageways emitted 3 to 4 times more gases than the GS cubicles system, despite feeding factors, with more methanogenous in the latter. The emission of nitrogen gases also seems more significant in the MS, probably due to the higher nitrogen content of the diet, which is based on alfalfa hay. However, the standard deviation of nitrogen emissions must be considered, which are high in the two systems. Conversely, for carbon emissions, the standard deviation appears smaller in the MS, as if the deep litter made the system more stabilized. Nevertheless, differences between the two systems are significant for the 4 gas emissions.

CONCLUSION: Measurements of GHG and ammonia emissions during two winter periods from two dairy system housings were performed easily by means of the simplified method we applied. However, water, phosphorous, potassium and nitrogen balances must be established to estimate the uncertainties of the measures and samples. When the GS building emits fewer gases than the MS, other measurements are needed to assess emissions from the slurry tank during the entire storage period. The manure management system starts in the barn and finishes at the field level.

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BIOAEROSOL AND DUST EMISSIONS FROM BROILE HOUSES

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ABSTRACT: In Germany during the last decade, great efforts were made to standardize sampling methods and analytical procedures for the quantitative determination of bioaerosols to ensure reliable and comparable results. To measure bioaerosol emissions, a sampling method based on an impinger device was standardized in the VDI guideline 4257 part 2. The measurement method and strategy will be presented and results obtained at three broiler houses during several complete fattening periods will be shown. Furthermore, at two broiler houses emission measurements of total dust, PM_{10} and $PM_{2.5}$ were performed, applying the VDI guidelines 2066 part 1 and 10. Performance characteristics for all compounds will be given.

Keywords: bioaerosols, emission, microorganisms, bacteria, molds, total cell count, dust, PM_{10}, $PM_{2.5}$, broiler houses, standardized measurement methods, emission impinger, VDI 4257 part 2, VDI 2066 part 1 and part 10

INTRODUCTION: A lack of information remains for the emissions of bioaerosols and particles (total dust, PM_{10}, $PM_{2.5}$) from broiler houses. In Germany, the number of broiler houses stocked with 30,000 animals and more is constantly increasing. In the vicinity of these plants people are concerned about bioaerosol emissions and resulting possible negative health effects. Accordingly, there is strong interest in gaining knowledge on the type and level of bioaerosol emissions during the fattening period.

In the last decade, to achieve valid and comparable measurement results, considerable efforts were made in the standardization of bioaerosol measurement methods, both for emissions and ambient air, including sampling and analytical procedures [1-6]. Meanwhile, a European technical specification is available for the determination of molds using filter sampling systems and culture-based analyses [7].

In the following, we present emission measurement results for different groups of microorganisms obtained at three artificially ventilated broiler houses stocked with 27,000 to 41,000 chickens, applying the standardized sampling and analytical methods. In addition, emission measurements of total dust and $PM_{10/\ 2.5}$ were performed at two of the investigated houses.

1. MATERIAL AND METHODS:

1.1. Investigated broiler houses: All measurements were performed at broiler houses in North Rhine-Westphalia, Germany from 2008 to 2010. The animals are kept according to a splitting procedure, which means that about one third of chickens are already housed out after 32 days while the rest of the animals remain an additional ten days in the poultry house. The plant parameters of the investigated broiler houses, as well as sampling periods and conditions, are compiled in table 1.

Table 1: Plant parameters and sampling periods.

Parameters	Plant 1	Plant 2	Plant 3
Floor area (m²)	1080	1800	1800
Number of animals before/after splitting	27.000/20.700	37.000/27.600	41.000/28.700
Max. animal mass (g)	~ 2400	~ 2600	~ 2300
Duration of fattening (days)	~ 40	~ 40	~ 40
Litter material	chopped straw	wood chips	chopped straw
Number of stacks	6 at the roof 3 side wall ventilators	10	16
Max. volume flow (m³/h)	~ 184.000	~ 240.000	~ 340.000
Measurement period (bioaerosols)	June – Nov. 2008	June – Nov. 2009	Sept. 2010 – Oct. 2011
Number of samplings (bioaerosols)	75	185	200
Measurement period (particles)		Sept. 2009 -Apr. 2010	April 2010 – Nov. 2010
Number of samplings (particles)		75	35

1.2. Measurements:

1.2.1. Volume flow: The ventilation system of broiler houses is regulated depending on the age of the animals and outside temperature. Therefore, the values of the volume flow vary within a great range from the beginning to the end of the fattening period and during the different seasons. Usually the fans of one plant are run in group switching, which means that one is controlled, whereas the others are either switched off or run at full load. To determine the actual volume flow, the exhaust velocity at full load was registered once a day and the exhaust velocity at the controlled fan was monitored continuously. The total volume flow was then calculated from the part volume flows of all fans in operation during the bioaerosol or dust samplings.

For the calculation of the concentration and volume flow at standard conditions (273 K, 101.3 kPa) the humidity and temperature of the exhaust gas were monitored and the outside pressure was measured.

1.2.2. Bioaerosols Bioaerosol sampling was performed isokinetically at one stack of each plant using the emission impinger according to [6]. Sampling solution for the deposition and enrichment of the bioaerosols was a cell-free NaCl/phosphate buffer. Per measurement day, 5 to 12 samplings were performed with a duration of 30 min each. After sampling, the probe tube and inlet tube of the impinger were rinsed with buffer solution because parts of larger particles are deposited in the inner surfaces. The rinsing suspension had to be added to the sampling suspension to prevent a quantitative underestimation of results. All sampling suspensions were cooled at 4°C until further cultivation which started, at latest, 24 h after the end of sampling. For the

determination of the total cell count, an aliquot of each sample was conserved with formaldehyde (final concentration = 3.4%). The following components were determined: culturable molds (25°C) [3], culturable mesophilic bacteria (36°C) [4], culturable staphylococci [8], culturable enterococci [9] and the microscopic detectable total cell count (fluorescent dye: DAPI) [5]. In total, about 450 samples were taken.

Bioaerosol samplings occurred once a week at plant 1 and twice a week at plant 3 during each fattening period. Plant 2 was investigated on three consecutive days at the beginning, in the middle and at the end of the fattening period.

1.2.3 Particles: Emission measurements of particles were performed at plants 2 and 3. The mass concentration of total dust and $PM_{10/2.5}$ were determined according to VDI 2066 part 1 [10] and VDI 2066 part 10 [11], respectively. The duration of sampling varied between 30 and 70 min to achieve ponderable masses on the quartz fiber filters. The $PM_{10/2.5}$-fractions were calculated with respect to the total dust concentrations.

2. RESULTS AND DISCUSSION:

2.1. Bioaerosols: In Figure 1 the concentration course for the analyzed compounds is depicted. Concentrations of culturable molds varied between 104 and 105 CFU per m³ exhaust air, with the highest concentration in the middle of the fattening period. Concentrations of culturable staphylococci and total culturable bacteria were about two orders of magnitude higher. After an initial increase, from week three a constant concentration level of about 107 CFU per m³ was determined. The average percentage of culturable staphylococci of the total culturable bacteria was about 50%. The total cell count was up to one or two orders of magnitude higher than the concentration of total culturable bacteria, resulting in values of up to 109 cells per m³.

The plant emission rates were calculated by multiplying bioaerosol concentrations and corresponding volume flows. To compare the emission rates of plants with different numbers of broilers, specific emission rates were calculated on the basis of livestock units (LU) (table 2). Specific bacteria emission rates rise from 105 cfu/(LU*s) after housing to 107 cfu/(LU*s) and remain constant from week 4 to the end of the fattening period. In contrast, the highest specific emission rates of culturable molds occur in week 3; afterwards the values decreased again. Lowest mold emission rates were observed in plant 2, where wood chips were used as litter material instead of straw. The Enterococci emission rates do not show any dependence from the duration of fattening and were emitted at a constant level of about 104 cfu/(LU*s).

Overall, the specific emission rates from the three investigated plants are in agreement. This is also proof for the validity of the measurement procedure, including sampling and analysis of microorganisms. The standard deviation calculated from parallel measurements according to VDI 4219 [12] was found to be 25% for bacteria, 15% for molds and 40% for the total cell count.

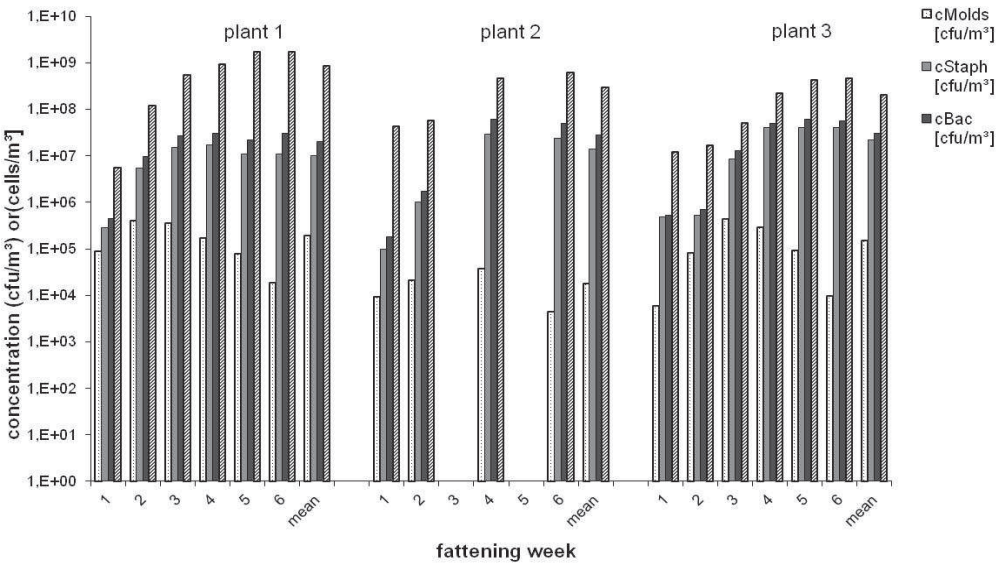

Figure 1: Concentration course of molds, staphylococci, bacteria and the total cell count during the fattening period at three broiler houses. The results of the single samplings were averaged to daily values and further on to weekly mean values.

Table 2: Specific emission rates of the investigated microorganisms at the three different plants (n.d. = not determined).

	$z'_{Bacteria}$ [CFU/(LU*s)]			$z'_{Staphylococci}$ [CFU/(LU*s)]			$z'_{Enterococci}$ [CFU/(LU*s)]		
fattening week	plant 1	plant 2	plant 3	plant 1	plant 2	plant 3	plant 1	plant 2	plant 3
1	1,1E+05	7,00E+04	2,0E+05	7,30E+04	1,5E+04	2,8E+04	n.d.	2,8E+04	6,3E+04
2	1,6E+06	3,70E+05	1,9E+05	9,20E+05	2,4E+05	1,5E+05	n.d.	2,6E+04	1,9E+04
3	7,5E+06	n.d.	4,2E+06	4,40E+06	n.d.	3,0E+06	n.d.	n.d.	8,9E+03
4	8,0E+06	9,20E+06	1,2E+07	4,50E+06	4,1E+06	1,1E+07	n.d.	3,3E+03	1,4E+04
5	5,0E+06	n.d.	1,5E+07	2,40E+06	n.d.	9,9E+06	n.d.	n.d.	8,4E+03
6	6,6E+06	1,30E+07	1,9E+07	2,40E+06	5,0E+06	1,4E+07	n.d.	8,2E+03	1,8E+04
Mean	4,8E+06	5,7E+06	8,4E+06	2,4E+06	2,3E+06	6,2E+06	n.d.	1,6E+04	2,2E+04

	z'_{molds} [CFU/(LU*s)]			$z'_{total\ cell\ count}$ [cells/(LU*s)]		
fattening week	plant 1	plant 2	plant 3	plant 1	plant 2	plant 3
1	2,2E+04	3,2E+03	3,6E+03	1,3E+06	1,6E+07	5,5E+06
2	7,1E+04	4,7E+03	2,3E+04	2,0E+07	1,2E+07	4,3E+06
3	1,8E+05	n.d.	1,1E+05	2,3E+08	n.d.	1,4E+07
4	4,1E+04	1,0E+04	5,1E+04	2,1E+08	8,3E+07	6,2E+07
5	1,7E+04	n.d.	2,2E+04	3,4E+08	n.d.	1,3E+08
6	3,4E+03	1,4E+03	2,1E+03	4,9E+08	2,0E+08	1,9E+08
Mean	5,6E+04	4,8E+03	3,6E+04	2,2E+08	7,8E+07	6,7E+07

2.2. Particles: Total dust concentrations increased from very low levels of under 1 mg/m³ at the beginning of the fattening period to 7 mg/m³ (plant 2) and 9 mg/m³ (plant 3) before housing out. Due to high volume flows occurring in the later fattening weeks, the particle emissions (mass flow) increase exponentially and reach values of more than 570 g/h in week 6. The measurement results at both houses are in agreement

The mean PM_{10} and $PM_{2.5}$ - fractions, which were calculated with respect to the total dust concentrations, were found to be 50% and 15%, respectively. A standard deviation of 13% was determined from parallel measurements of total dust.

All results are summarized in table 3.

Table 3: Concentrations, emissions and specific emissions of particles at two different plants.

Fattening week	Concentrations [mg/m³]	Mass flow [g/h]	Specific emission rate [g/(h*LU)]
Plant **2**			
1	0,7	2	0,4
2	3,2	67	2,2
3	4,2	118	2,8
4	5,0	362	3,4
5	5,1	313	2,8
6	6,9	566	4,4
mean	4,2	238	2,7
Plant **3**			
1	0,8	10	1,3
2	1,2	30	1,1
3	2,2	75	1,4
4	5,7	260	2,6
5	9,4	640	5,7
6	9,2	580	5,3
mean	4,8	266	2,9

CONCLUSION: The application of standardized measurement methods leads to reproducible and comparable measurement results. The bioaerosol and particle data presented here are a basis for further investigations on animal house emissions. Important issues are the assessment of the efficiency of reduction measures for bioaerosols and dust in broiler houses, and the calculation of plant-related bioaerosol ambient air concentrations using dispersion modelling.

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A LARGE-SCALE STUDY OF ON-FARM METHANE EMISSIONS BY INDIVIDUAL DAIRY COWS DURING MILKING

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ABSTRACT: Methane emissions vary among research cows, even when fed the same diet, suggesting that emissions would vary considerably on commercial farms. The objective of this on-farm study was to quantify between- and within-cow variation in methane emissions, and to identify factors related to this variation. Methane emission rate during milking (MERm) was recorded using methane analyzers installed in robotic milking stations for 215 cows over a period of five months to provide 14,533 daily means. This dataset of continuous methane estimates enabled us to look at changes in the methane emission rate with days in milk on a continuing basis. Between-cow variation in MERm (mean 2.07, SD 0.629g/min) was greater than within-cow variation and was related to variation in live weight, milk yield, parity, and week of lactation. A total of 72 sires were identified for 164 daughters in the dataset and a significant sire effect on MERm supports the hypothesis that methane emissions have a genetic component. Estimation of daily methane emissions from MERm data, using an equation derived from respiration chamber work, produced estimates that ranged from 278 to 456 g CH_4/d and were commensurate with values predicted from energy requirements for observed live weight and milk yield throughout lactation. It is concluded that methane emissions vary considerably between dairy cows housed under commercial conditions. This variation needs to be included when performing inventories or testing mitigation strategies, and might offer opportunities for genetic selection.

Keywords: methane, individual variation, on-farm, dairy cow

INTRODUCTION: National methane inventories assume a fixed factor for all cows or estimate methane output from GE intake predictions (IPCC, 2006). However, methane emissions vary with DMI (Grainger et al., 2007) and diet composition (Beauchemin et al. 2009), and even vary among individuals fed the same diet (Grainger et al., 2007). The objective of this on-farm study was to quantify between- and within-cow variation in methane emissions, and to identify factors related to this variation.

1. MATERIAL AND METHODS: Holstein-Friesian cows (average annual milk yield 10,000 L/cow) were group-housed in a freestall barn and milked at robotic milking stations, on average, 2.8 (SE 0.37) times per day. Cows were fed ad libitum on a total-mixed ration (0.32 maize, 0.13 grass and 0.12 whole-crop silages; 0.05 straw, 0.1 sugar beet pulp, 0.13 rape, 0.08 soya, 0.02 fat, 0.04 minerals) plus concentrates during milking (1.6 kg/d plus 0.16 kg/kg milk yield above 23 L/d). Methane emission rate during milking (MERm) was calculated from the frequency of eructations and their methane content, as measured using an infrared methane analyzer that sampled air from feed bins in the milking stations. MERm was recorded

at each milking for 215 cows over a period of five months to provide 14,533 daily mean values. Not all cows were present for the whole

5-month period, due to cows calving, being dried off or culled. Cow pedigrees were used to identify a total of 72 sires for 164 daughters in the dataset.

For comparison with prediction equations, daily methane emissions were estimated from MERm data using the equation:

Methane emissions (g/d) = 252 + 57.2 × MERm (g/min).

This equation was obtained using 12 cows monitored on-farm and subsequently in respiration chambers (Garnsworthy et al., 2012).

To compare MERm-estimated methane emissions with conventional estimates, methane emissions were predicted as 6.5% of estimated GE intake. GE intake was estimated by using IPCC (2006) Tier 2 and Feed into Milk (FiM; Thomas, 2004) equations. Estimated and predicted methane emissions were compared using Lin's Concordance (Lin, 1989).

Statistical calculations were performed using Genstat 14 (Lawes Agricultural Trust, UK). Weekly mean MERm data were analyzed as linear mixed models, including repeated measures using the residual maximum likelihood (REML) procedure. The model fitted fixed effects for live weight, milk yield, parity and week of lactation. For the random effects, individual cows represented subjects, and weeks of the study represented time points for repeated measures. Correlations between successive measurements on the same cow were assumed to decrease with the time interval between measurements, so an autoregressive error correlation model of order 1 was used.

For the subset of 164 cows with identified sires, the same mixed model was used, with sire added as either a fixed or a random effect so that sires could be considered either as a specific set (fixed) or drawn at random from an infinite population (random).

To examine changes in methane emissions with week of lactation, non-linear regression analysis was performed on fitted means using an asymptotic model with a linear trend ($Y = A + B(RX) + CX$), where X is week of lactation and A, B, C and R are constants.

2. RESULTS AND DISCUSSION: Across the 5-month monitoring period: days in milk ranged from 1 to 366 (Mean 161, SD 98); milk yield ranged from 4 to 72 L/d (Mean 33, SD 9.1); live weight ranged from 373 to 813 kg (Mean 602, SD 70); lactation number ranged from 1 to 12 (Mean 3, SD 1.6).

Frequency of MERm means, averaged for each individual cow across the study, followed a normal distribution (Figure 1) with a mean of 2.07 (SD 0.629) g CH_4/min and a range from 0.57 to 3.6 g CH_4/min.

When the mixed model was fitted to MERm data, significant fixed effects were found for live weight ($P<0.001$), milk yield ($P<0.001$), parity ($P=0.002$), and week of lactation ($P=0.016$). It is likely that these effects are mediated through increasing DMI with increasing live weight and milk yield, although DMI could not be measured in the current study.

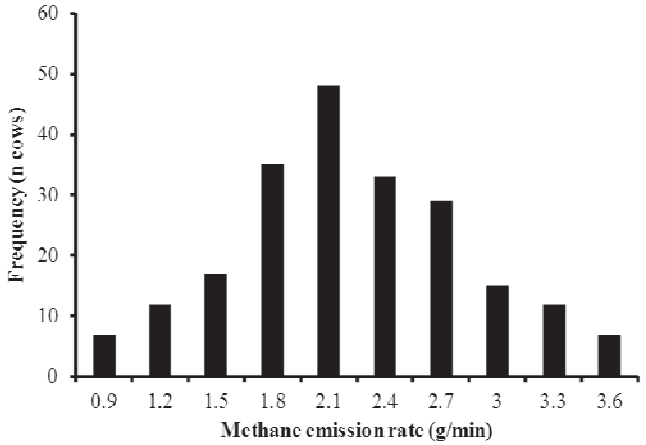

Figure 1. Frequency distribution of individual cows according to average methane emission rate during milking over a 5-month period.

The random component for variation among individual cows (0.23, SE 0.03) was greater (P<0.001) than the residual component within cows (0.06, SE 0.02), suggesting that MERm estimates result from real and consistent differences between cows in their rate of methane emissions by eructation during milking. The CV for MERm in the 215 cows observed over 5 months, estimated from variance components of the mixed model, was 18.9 % between cows and 11.5% within cows. These values are of similar magnitude to CVs for methane emissions found by Vlamming et al. (2005) and Grainger et al. (2007).

When sire was included in the model as a random effect for cows with known pedigree, the sire variance component was not significant (P=0.136), but sire was significant (P=0.025) when included as a fixed effect. Lack of significance for a random sire effect can be explained by the low level of replication within sires. The significant fixed sire effect and the consistent differences between cows across the study are encouraging for possible genetic selection.

Non-linear regression analysis of model-fitted weekly means produced the equation: Daily methane emissions (g CH_4/d) = 407 – 103×(0.86W) – 0.63×W,

where W = week of lactation. The shape of this curve is consistent with expected changes in DMI and diet composition throughout lactation.

Mean daily methane emissions for each week of lactation estimated from MERm are compared to values predicted from milk yield and live weight data using IPCC (2006) and FiM equations in Figure 2. IPCC (2006) overestimated emissions in early lactation by up to 20% and underestimated emissions in later lactation by up to 7%. FiM overestimated emissions in early lactation by up to 8% and underestimated emissions only in week 1 of lactation by 3%. Lin's concordance coefficients for comparison to MERm-estimated methane were -0.13 (P >0.05) for IPCC predictions, and 0.63 (P <0.05) for FiM predictions. Overall means were 379 (SD 16.4) g CH_4/d for MERm-estimated methane, 383 (SD 18.7) g CH_4/d for IPCC-predicted methane, and 383 (SD 14.4) g CH_4/d for FiM-predicted methane.

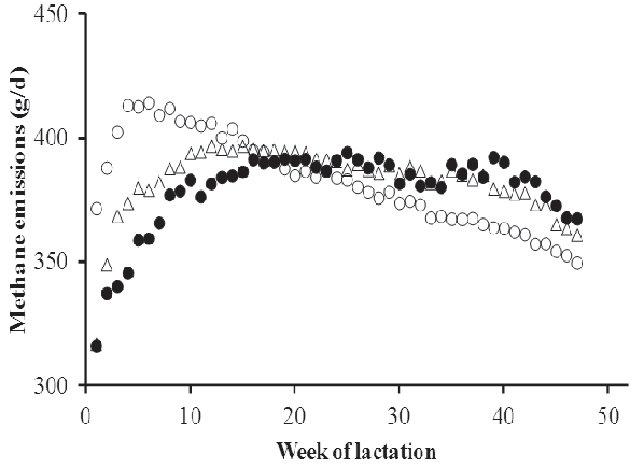

Figure 2. Daily methane emissions for each week of lactation estimated from individual MERm values (●), or predicted using IPCC (○) or FiM (Δ) equations.

CONCLUSION: Methane emissions vary considerably between dairy cows under commercial conditions. This variation is related to live weight, milk yield, parity and week of lactation, in accordance with changes in ME requirements. This variation needs to be included when performing inventories or testing mitigation strategies.

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AMMONIA AND GREENHOUSE GAS EMISSIONS IN PIG FATTENING ON SLATTED FLOOR WITH EXCREMENT DISCHARGE BY FLAT SCRAPING

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ABSTRACT: Gas emissions (NH_3 GHG) from four pig fattening rooms on slatted flooring with flat scraping and under-floor air evacuation were measured in three consecutive batches between May 2009 and June 2010 in the experimental station of Crecom (France). Gas concentrations and ventilation rates were measured and recorded during 3 periods of 14 days during the breeding period (day 7 to 21, 35 to 49 and 63 to 77). Gas concentrations were measured with an infrared photoacoustic monitor (INNOVA 1412) in the room area. Manure was scraped once a day and stored in the breeding rooms for two weeks. Measured carbon emissions (C-CH_4 and C-CO_2) were validated by comparison with the C mass balance deficit, whereas measured nitrogen emissions (N- NH_3 and N-N_2O) were not validated by comparison with the N mass balance deficit. Observed differences between measurement and mass balance deficits were explained by the sampling point site for concentration measurements that was not representative of the exhaust air. With additional experiments, we demonstrated that ammonia concentrations measured in the exhausted air were 51 % higher than those measured in the room. Under-floor air evacuation combined with a flat scraper system enabled the reduction of ammonia concentrations in the room and improved air quality and the working environment. However, compared to a slurry storage system, a flat scraper system with manure stored in the room after scraping, reduces GHG emissions (N_2O and CH_4) in the exhaust air, but can increase NH_3 emissions.

Keywords: GHG, NH_3, pig, emissions, flat scraper

INTRODUCTION: In France, concrete slatted floor is used in 95% of fattening pig houses. With this type of floor, either slurry is stored in a pit under the slats for the duration of the entire fattening period or slurry is frequently removed. According to bibliography, the use of a frequent slurry removal system has several advantages compared to a stored slurry system. This system enables limiting gas and odour formation by reducing the duration time that manure is stored inside the buildings (Guingand, 2000) and improves animal performance (Landrain et al. 2010). Among the different frequent manure removal systems, the flat scraper system is a mechanical system. It consists of a shallow slurry pit with a horizontal steel scraper under the slatted floor, allowing the manure to be removed from the building several times a day (Groenestein, 1994). This system was established in four fattening pig rooms in the experimental station of Crecom (France) and ammonia and GHG emissions were studied in three batches.

1. MATERIAL AND METHODS:

1.1. Animal and experimental design: Three successive batches of pigs from May 2009 to June 2010 were fattened in four identical pig fattening rooms equipped with a flat scraper system in the experimental station of Crecom (France). In each room, 88

pigs were group housed in 8 pens. In two rooms (A and B), pigs were offered liquid food with three meals per day at 6 am, 12 pm and 5.30 pm (restricted ration). Each meal has a dilution rate of 2.2 liters of water per kg of food. In the two other rooms (C and D), pigs were offered dry food on an ad libitum basis (unrestricted ration) and have permanent water accessibility. In the two rooms with the same feeding system, one has an animal density of 1 m² per pig and the other an animal density of 0.7 m² per pig (Table 1).

Table 1. characteristics of the experimental rooms.

Item	A	B	C	D
Animal density (m²/pig)	1	0,7	0,7	1
Feeding system	liquid	liquid	dry	dry

Manure was scraped once a day and stored in breeding rooms for two weeks. Fresh air entered via a ceiling of perforated plastic sheeting and air exhaust was an under-floor extraction chimney. Pigs were weighed at the beginning and end of each batch and each measurement period, enabling the measurement of individual average daily gains. Food and water intake were registered for each batch and each measurement period to determine the food conversion ratio.

1.2. Measurements: Gas concentrations (ammoniac, nitrous oxide, methane, carbon dioxide and water) were measured inside and outside the room with an infrared photoacoustic monitor (INNOVA 1412) during the breeding period: day 7 to 21 (period 1), 35 to 49 (period 2) and 63 to 77 (period 3). Gas measurements were made every 12 minutes during the three measurement periods. Gas concentration is expressed as mg/Nm^3. The temperature (°C) and hygrometry (%) inside and outside were measured continuously and the air flow rate, expressed as m^3/h/porc, was calculated with CO_2 balance. Gas emissions, expressed as g/pig/day, were calculated by dividing cumulated emission for each gas per day and per pig. To validate emission factors, measured carbon emissions (C-CH_4 and C-CO_2) were compared with the C mass balance deficit. Additionally, measured nitrogen emissions (N-NH_3 and N-N_2O) were compared with the N mass balance deficit. The C and N mass balance deficit were calculated according to the following formula:

Mass balance deficit (N or C losses by volatilization) = input (piglet carcass, food consumption) – output (pig carcass, slurry composition) (1)

An analysis of variance (R) was performed to test the effects of period, animal density and feeding system.

2. RESULTS AND DISCUSSION:

2.1. Gas concentrations: The overall average N_2O, NH_3 and CH_4 concentrations were, respectively, 1,25 ± 0,22, 9,05 ± 2,84 and 4,75 ± 1,27 mg/Nm^3. There was no effect of animal density and period on gas concentrations. Statistical analysis could not be performed to test the effect of the feeding system due to a technical problem in the monitor for two batches with liquid feeding. However, it seems that NH_3 concentrations were lower with liquid food than with dry food**.**

Compared to NH_3 concentration measured in the room with a slurry stored system, an under-floor air extraction was 13,45 mg/m^3 (Guingand, 2000), indicating the flat scraper enables a 32% reduction of the NH_3 concentration in the room.

2.3. Gas emissions: Carbon emissions (C-CH_4 and C-CO_2) explained about 87.5% of carbon losses by volatilization (carbon mass balance deficit), with a 78.3% minimum and a maximum of 102.5%. This means that CH_4 emission factors could be validated. Nitrogen emissions (N-NH_3 and N-N_2O) explained about 47.6% of the nitrogen losses by volatilization (nitrogen mass balance deficit), with a 20.3% minimum and a maximum of 81%. According to these results, NH_3 and N_2O emission factors could not be validated. With additional experiments, we demonstrated that NH_3 concentrations measured in the exhausted air were 51 % higher than those measured in the room (Figure 1), whereas N_2O and CH_4 concentrations were not disturbed by the under-floor ventilation system.

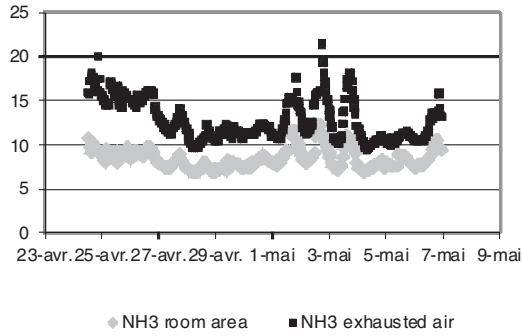

Figure 1. Comparison NH_3 concentrations (mg/Nm^3) in the room and in exhausted air.

Observed differences between measurement and mass balance deficits were explained by the sampling point site for concentration measurements that were not representative of the exhaust air. N_2O and CH_4 emission factors were estimated with measurement and NH_3 emission factors were estimated with N mass balance deficit and calculated according to the following formula:

NH_3 emission (g/pig/day) = 17/14 x (N mass balance deficit – N-N_2O measured) /pig/day (2)

Table 2. gas emissions (g/pig/day).

Item		N_2O	NH_3	CH_4
Measure period	7 to 21 d	0,30 ± 0,08	5,35 ± 0,99	1,74 ± 0,94
	35 to 49 d	0,35 ± 0,13	9,71 ± 2,29	2,61 ± 1,04
	63 to 77 d	0,57 ± 0,35	12,20 ± 2,82	3,85 ± 1,81
	average	0,41 ± 0,24	9,09 ± 3,56	2,73 ± 1,54
	Min	0,17	4,33	1,09
	Max	1,12	15,88	7,69
Feeding system	Liquid	0,43 ± 0,27	9,65 ± 3,71	3,07 ± 1,57
	Dry	0,33 ± 0,07	7,39 ± 2,62	1,71 ± 0,94
Animal density	1 m²/porc	0,45 ± 0,23	8,63 ± 2,93	2,60 ± 1,26
	0,7 m²/porc	0,36 ± 0,25	9,55 ± 4,18	2,86 ± 1,82

After validation for the three batches, N_2O emission factors vary between 0.17 and 1.12 g/pig/day and CH_4 emission factors vary between 1.09 and 7.69 g/pig/day (estimated with measurement). NH_3 emission factors vary between 4.33 and 15.88 g/pig/day (estimated with N mass balance deficit). The average N_2O and CH_4 emission factors, respectively, of 0.41 ± 0.24 and 2.73 ± 1.54 g/pig/day were inferior by, respectively, 77% and 72% to the reference emission factors of 1.74g N_2O /pig/day and 9.85g CH_4/pig/day in GES'TIM (Gac et al, 2010). However, an 18% augmentation in comparison with the reference ammonia emission factor (7.68g/pig/day) calculated from the excreted azote given by CORPEN (3.79 kg/pig) and from the percentage of excreted azote under the form of ammonia of 22.5% excreted N . This result is consistent with the bibliography since Philippe et al (2011) found that the frequent dejection evacuation system by flat scraping does not seem to have any positive effect on ammonia emissions. We observe an augmentation of NH_3 and CH_4 emission factors from period 1 to period 3 for each room and each batch. According to the results, dry food engenders a reduction of N_2O, NH_3 and CH_4 emissions in comparison with liquid food. Moreover, a smaller density (0.7 m^2/pig) engenders a reduction of N_20 emissions, but promotes augmentation of CH_4 and NH_3 emissions.

CONCLUSION: Compared to a stored slurry system, frequent manure removal with a flat scraper enables improvement of room quality and thus of the workers' and animals' environment with a reduction of ammonia concentration in the air. This system also enables considerable reduction of (more than 70%) GHG (N_2O and CH_4) emissions compared to national reference factors. However, high ammonia volatilization was generated under the slats, which increased NH_3 emissions by 18% with this system compared to a stored slurry system. This result can be explained by storage of the removed manure in the breeding rooms for two weeks, by the small film left on the floor after scraping or by the ventilation system.

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ANALYSIS AND MEASUREMENT OF ODOR EMISSIONS FROM AGRICULTURAL BIOMASS BURNING

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ABSTRACT: Biomass burning may cause nuisance odor and represents one of the most critical sources of odor complaint. The present study aims to explore the potential of biomass to create discomfort and problems related to odor emissions during combustion of four biomasses: switchgrass, willow, the solid fraction of pig manure (FSLP) and wood. A small-scale simulation was developed to measure odors. The odor samples were analyzed by dynamic olfactometry. The results showed that odor of the three agricultural biomasses had a better hedonic character than wood pellets. Analysis of odors emitted by combustion showed that the odor resulting from FSLP was the least pleasant while the combustion of switchgrass was the most enjoyable. Agricultural biomass combustion does not cause greater olfactory trouble than wood combustion. Thus, in terms of cohabitation, utilization of biomass for energy production is feasible.

Keywords: agricultural biomass, burning, odor emissions, green energy

INTRODUCTION: Regarding current climate issues, biomass combustion is a recommended technology for reducing fossil fuel consumption. It is, however, a source of fine particles, carbon monoxide, nitrogen oxides and volatile organic compounds, including toxic and carcinogenic constituents (SOTF, 1995). Agricultural and forest biomass burning is a potentially interesting avenue for the production of usable energy to replace expensive and nonrenewable fossil fuels. Combustion allows the generation of heat due to the complete oxidation of fuel with an excess of air. Biomass fuel could be a food that comes from animal or plant production. This would optimize animal waste management and reduce dependence on fossil fuels. To fulfill the demand for bioenergy as well as enhance wasteland, there is a current desire to produce pellets from switchgrass and willow. Jacobson (1995) promotes solid swine manure and cattle manure. Granules also exist within the agricultural sector. According to Godbout et al. (2010), forest and agricultural biomass were the most widely used sources. The main aim of this study was to quantify, evaluate and compare odorous emissions from burning various agriculture and forestry biomass.

1. MATERIAL AND METHODS:

1.1. Biomass: Four biomasses were evaluated: the grain of willow, FSLP, switchgrass and wood (table 1).

Table 1. Characteristics of tested biomass (Villeneuve et al., 2011).

	Willow	Switchgrass	FSLP	Wood
Caloric value (MJ/kg)	19.6	18.6	15.0	20.5
Carbone rate (%)	48.4	47.8	45.7	51.9
Hydrogen rate (%)	5.9	5.76	6.45	5.7 - 6.1
Nitrogen rate (%)	0.53	1.17	3.45	0.09- 0.4

The measurement of odor was performed by dynamic dilution olfactometry, involving a self-made diluting device (olfactometer) and a panel of six people, who determine the odor threshold (Hudson and Ayoko, 2008a, b). The pre-diluted odor sample was mixed with purified air (active carbon, particulate filter and silica gel), in ratios ranging between 1 and10.

1.2. Calculation of odor emissions: The calculation of odor emissions was measured through the formula:

$$E= (C_{od} * Q)/(CV* R_{comb})$$

Where: E= odor Emission (UOE/MJ), C_{od}= odor concentration (UO_E/m^3),
Q= Air flow in the chimney (m^3/mn), CV= biomass calorific value (MJ/kg) and R_{comb}= combustion rate (kg/mn)

1.3. Statistical analysis: Odor units (UO) are evaluated on a continuous scale by the panelists. A normal linear mixed model was fitted to the natural logarithm of odor units with the MIXED procedure of SAS (9.13). Data were log transformed for a normal distribution and a homogeneous variance.

$$\log(UO_{ijk}) = \mu + \beta_i + d_{ij} + e_{ijk}$$

Where: $\log(UO_{ijk})$ is the log of odor units evaluated by the panelist k for biomass i the day of the test session j, μ is a reference parameter, β_i is the fixed effect of biomass i, d_{ij} is the random effect of evaluation day for biomass i, and e_{ijk} the residual error due to panel k for biomass i in the session j.

2. RESULTS AND DISCUSSION:

1.1. Odor units analysis: Odor refers to the aggregate effect of a mixture of gases on the sense of smell. Odor threshold is defined as the concentration at which 50% of a group of panelist can smell it. It is the composite of over 170 trace compounds (Sweeten et al., 2006). Figure 1 shows the odor intensity (odor units) measured by a trained human panel. We note that the majority of panelists discerned UO_E values between 0 and 20000 and two panelists had a threshold of combustion odor perception of 35,000UO_E.

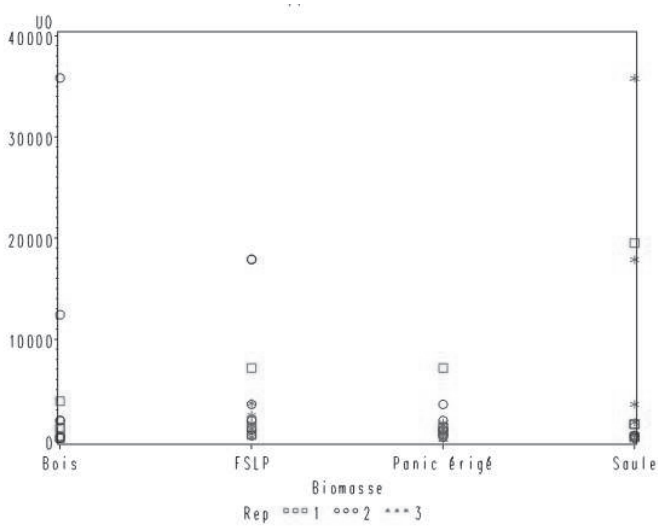

Figure 1. Analysis of odor units by biomass.

The odor threshold for biomasses is very different. Table 2 shows that the averages of UO_E range from 956 to 2024 UO for switchgrass and FSLP, respectively, with minimum and maximum values of 443.5 and 4341.6 UO.

Table 2. Odor units means and of 90% confidence interval limits.

Biomass	Means	Lower limit	Upper limit
Wood	1492.10	588.293	3784.47
FSLP	2024.42	943.947	4341.63
Switchgrass	956.42	443.465	2062.69
Willow	1096.58	514.494	2337.21

1.2. Odor emissions: Intensity describes the strength of an odor and is measured at concentrations above the detection threshold (ASCE, 1995). Odor emissions are reported in Table 3. It appears that emissions range from 2937 for FSLP to 277UO_E/MJ for willow. FLSP presented the highest odor concentration. Due to the complex composition of odors, variable sources, environmental factors, and varying human perceptions of offensive smells, it is difficult to measure odors and determine a reasonable objective threshold limit for odor emissions from large scale operations.

Table 3. Odor emissions (UOE/MJ).

	Means	Lower limit	Upper limit	Pr>|t|
Wood	1390	294.630	6558.01	
FSLP	2937	825.924	10446.66	0.504
Switchgrass	1245	348.677	4446.63	0.920
Willow	277	78.291	982.00	0.171

No significant difference was reported for comparison between the different biomasses. As a result, emissions of different biomasses did not differ from emissions from wood combustion, which allows their use as fuel in the same manner. To analyze odor emission logs, we note that the majority of biomass has values at a logarithmic scale between 5 and 11, except the willow with values between 0 and 11 (Fig. 2). However, for testing association between hedonic trait and type of biomass, it emerged that FSLP gave an odds ratio slightly higher compared to other biomasses without being significantly different.

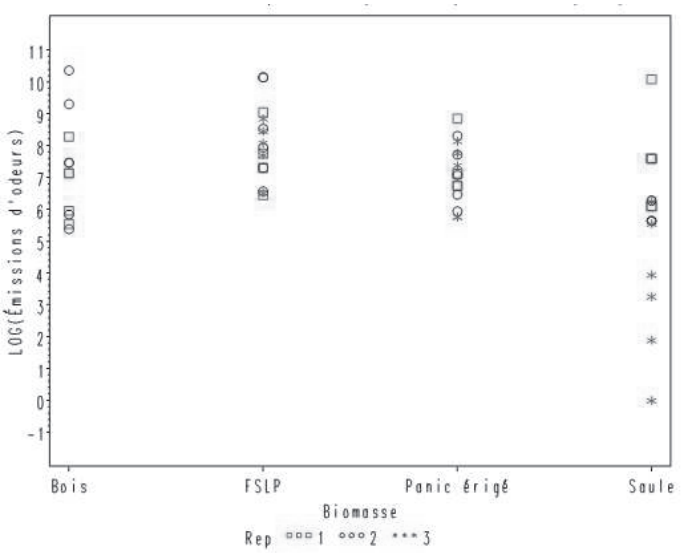

Figure 2. Analysis of odor emissions log.

CONCLUSION: Biomass combustion is a promising technique for producing green energy. However, to ensure that this remains an interesting alternative for energy and environmental plans, the evaluation of agricultural and forest biomass odorous emissions from combustion is increasingly important. This study shows there is no significant difference in odor emission between wood and used biomass. Therefore, biomass combustion is acceptable for use as an energy source. With the use of a panel, the dilution of the odor is composed according to specific protocol and the panelists' responses are analyzed to evaluate odor intensity. This method is under constant development and is considered the world reference for the normalization of intensity measurement.

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CONTRASTED GREENHOUSE GAS EMISSIONS FROM STORED SOLID MANURE PRODUCED IN TIE-STALL AND DEEP LITTER BARNS

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ABSTRACT: Animal housing systems may induce variability in manure characteristics and greenhouse gas (GHG) emissions during their storage. Because of the dynamic chambers, methane (CH_4) and nitrous oxide (N_2O) emissions were measured from contrasted solid manure stored at two different periods of the year (colder: C and warmer: W). Solid manure came from tied-stalls (TS) and from deep litter (DL) for Blue White heifers showing similar dry matter ingestion (DMI). Straw was supplied for bedding in respectively low and high amounts in function of the housing system (TS: 0.1 and DL: 1 kg of fresh matter per 100 kg animal live-weight). Manure was scrapped daily in TS and stored outside while it accumulated for a longer period in barns in DL. Significant ($p<0.05$) effects of the housing systems and the periods of storage were observed in the GHG emissions with, by far, higher emissions from DL compared to TS, and higher emissions when manure was stored during the W compared to the C periods (TS-C: 1±1, TS-W: 45±17, DL-C: 173±24, DL-W: 631±100 g CO_2eq/kg DMI). These results indicate that the housing systems strongly influence GHG emissions during solid manure storage. For diverse reasons (animal welfare, consumer expectation), shifts in housing systems from low to high straw input as bedding could be promoted, but that would probably lead to an increase in GHG emissions from solid manure stores. When possible, storage of solid manure during warm periods should be avoided.

Keywords: greenhouse gas emissions, solid manure, storage, season, barn type

INTRODUCTION: Diversity in animal housing systems, cattle diets, manure management and storage conditions induce variability in manure characteristics and greenhouse gas (GHG) emissions during storage. However, there is a lack of data and models for estimating GHG emissions from stored solid manure (Webb et al., 2012). In this context, trials were performed that focus on GHG production in the barn and during solid manure storage in suckler cow systems. GHG emissions from two contrasted housing systems were measured. The two contrasted housing systems were tie-stall (TS) and deep litter (fully strawed cattle area, DL). Several of the results concerning TS systems were published elsewhere (Mathot et al., 2012), with detailed methodology description, while in this contribution we target comparison of GHG production during the storage of solid manure produced in TS and DL.

1. MATERIAL AND METHODS: During winter 2009-2010, 16 Blue White heifers were raised in 4 experimental barns of 4 heifers each. There were two TS and two DL. TS and DL were strawed daily with target values of straw supply of, respectively, 0.1 and 1 kg of fresh matter per 100 kg animal live-weight per day. Solid manure from TS were removed daily while the solid manure from the DL systems were accumulated for a more (70 days) or less (20 days) longer period in barn. Small amounts of liquid

manure were collected in TS barns (about 5% of the organic matter produced) and were not included.

One experimental barn was attributed to each group of 4 heifers. In TS, two contrasted diets were tested (see Mathot et al., 2012) while two removal frequencies of solid manure were tested in DL; only at the end of the experiments (1X) or 3 times during the trials (3X, table 1). The heifers of the DL systems received the same diet as those of the TS systems. Within one type of housing system, treatments were crossed with heifer group during the winter, leading to manure storage outside the barn during colder (C) or warmer (W) conditions. For a given period, the solid manure was removed from the stores on the same date, leading to longer storage duration for solid manure from TS. Solid manures were stored independently on concrete storage facilities, allowing the use of large (c.a.11m²) dynamic chambers (hood) equipped with a fan with a full-size anemometer for controlling and measuring air flows. Gaseous emissions from manure stores were performed with a photoacoustic multi-gas analyser 1412 and a multi-point sampler 1309 (Lumasense Technologies SA, Ballerup, Denmark) configured for CO_2, CH_4, N_2O and H_2O air concentration measurements.

Table 1. Overview of the origins of the solid manure, storage starting date, duration and outside temperature (Out .temp). D1 and D2 refer to two different diets and 1X and 3X to the removal frequency of the solid manure from the DL barns. C (cold) and W (warm) to the storage period.

		Tie-stall (TS)		Deep litter (DL)	
Period	Parameters	Herd a	Herd b	Herd c	Herd d
C	Barn treat.	D1	D2	D2, 1X	D2, 3X
	starting date	17/11/2009	17/11/2009	28/01/2009	10/12/2009[1]
	Duration (d)	136	136	64	113
	Out. temp. (°C)	1.2±0.4	1.2±0.4	1.7±0.6	0.1±0.4
W	Barn treat.	D2	D1	3X	1X
	starting date	9/02/2010	9/02/2010	11/03/2010[1]	4/05/2010
	Duration	146	146	112	62
	Out. temp. (°C)	8.3±0.6	8.3±0.6	10.6±0.5	13.3±0.7

[1]Date of the first manure removal

For each heap of solid manure, measurements were taken, on average, every three days during 3 to 24 hours and extrapolated to 1 day, when necessary. The trapezoidal rule was used to estimate daily emissions for the days without measurements. Emissions over the period were calculated by adding the daily emissions of a given heap. Between measurements, the hoods were removed and the heaps remained uncovered. Chemical analyses and weighing were performed to allow mass nutrient balances calculation. C emission measurements were compared with C mass balance for emission measurements validation. Heaps' temperatures were recorded at each

gaseous emissions measurement using 4 thermometers located c.a. 0.3 meter deep in the manure. Results were analysed (R Development Core Team, 2011) using an ANOVA 2 model with housing systems (n=2) and periods of storage (n=2) and their interaction as fixed factors and after a logarithmic transformation of the data for gaseous emissions. Emissions data were related to heifers' dry matter ingestion (DMI) to reduce interference effects due to animal size and housing duration. Means are presented with their standard error.

2. RESULTS AND DISCUSSION: There were no significant differences ($p>0.05$, data not shown) in cattle diets' composition (protein, energy,…) or ingestion (kg DM/kg metabolic weight) between housing systems. Between 5.3 and 8.8 10^3 kg of fresh manure was stored and a strong ($p<0.05$) influence exists among the housing system and the amount of manure dry matter produced (TS= 427±12 g/kg DMI; DL=747±24 g/kg DMI), the solid manure dry matter (TS=180±10 g/kg fresh manure; DL=257±10 g/kg fresh manure) and nitrogen concentrations (TS=33±1 g/kg dry manure; DL= 29±1 g/kg dry manure). The GHG emissions were significantly ($p<0.01$) influenced by the housing systems and by the storage periods and their interaction ($p<0.01$, figure 1).

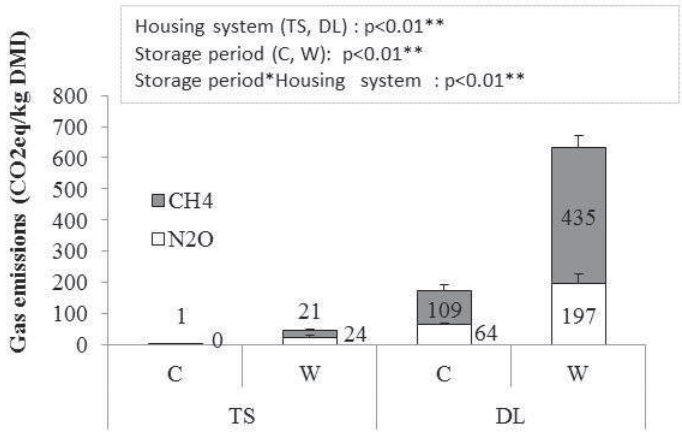

Figure 1: Mean (n=2) GHG emissions from stored solid manure (in CO_2eq using global warming potential of 25 for CH_4 and 298 for N_2O, IPCC 2007) in function of the housing system (TS: Tied stall and DL: deep litter) and the period of storage (C=cold season and W=warm season).

On average, <1, 3±1, 10±1 and 39±6 g/kg of the C stored was lost as C-CH_4 and <0.1, 1.8±0.5, 3.2±0.1 and 9.5±1.6 g/kg of the N stored was lost as N-N_2O from TS-C, TS-W, DL-C and DL-W, respectively.

As validation of gaseous emissions, carbon mass balances at storage were calculated and compared to total C emissions measured (C-CO_2+C-CH_4). After correction of emissions according to the difference between the mass balance and the C emissions measured, the housing systems and period effects remains significant, but the GHG emissions were 1±1, 54±7, 152±26, 481±43 g CO_2eq/kg DMI for TS-C, TS-W, DL-C and DL-W, respectively. Total GHG emissions were strongly related (relation not shown, $p<0.001$) to heap average temperatures. The higher temperatures observed in DL (43±6°C) compared to TS (10±3°C) and to outside temperatures (table 1) are evidence of high microbial activity in the heaps. The high average temperatures in the

DL heaps are also indications that microbial activity was still significant at the end of storage periods; therefore, even more GHG emissions could be expected when this manure was kept in storage for a longer duration. This hypothesis is confirmed by the kinetic of emissions for DL heaps stored during the warmer period (not shown). Furthermore, emissions from DL in barn are not considered, while they were negligible in TS (Mathot et al., 2012). These results indicate that even when including variability (diet or manure removal frequency) and even when the solid manure from TS had higher N concentrations and was stored for longer durations, it emitted far less GHG than solid manure produced in DL.

CONCLUSION: GHG emissions from cattle excretion during outside storage is strongly influenced by housing system and storage conditions. Changes in animal housing systems to improve animal welfare or to answer consumer expectations by using large amounts of straw as litter could increase GHG emissions from manure stores. When possible, storage of solid manure during warm periods should be avoided.

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MOLECULAR ANALYSIS OF EMISSIONS FROM BROILER HOUSES

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ABSTRACT: This paper describes investigations about the characterization of bacterial emissions from broiler sheds by cultivation-independent methods.

Keywords: broiler houses, emission, bacteria, 16S rRNA gene sequence, clone library, qPCR

INTRODUCTION: Poultry processing plants are considerable sources of microorganism emissions (Seedorf et al., 1998). However, microorganism emissions from livestock buildings are rarely characterized, especially in their microbial composition as well as their environmental impact. In particular, residents living in areas surrounding poultry processing plants are increasingly interested in this characterization because of a postulated negative health effect through bioaerosol exposure (Gärtner et al., 2009). Therefore, we investigated the microbial load and the bacterial composition in emission samples from broiler sheds by cultivation-independent analysis.

1. MATERIAL AND METHODS: Stack emissions were sampled from a broiler house which comprised ~ 40000 animals. Distributed over 2.5 fattening periods, emission samples were collected by an isokinetically sampling procedure via impingement into isotonic cell free NaCl solution according to the German VDI 4257 part 2. The specific emission rate was determined by considering the total cell count analyses of the obtained bioaerosol-suspensions (according to VDI 4253 part 4) and the exhaust emission flow. For investigating bacterial composition cells of 1 ml, bioaerosol-solution was concentrated into bioaerosol-pellets by centrifugation, which was used for DNA extractions and subsequent amplifications of 16S rRNA genes, as described elsewhere (Martin et al., 2010a).

2. RESULTS AND DISCUSSION: Microorganism concentrations in emission samples clearly increased during the fattening period, from 4 x 10^7 cells per m^3 at the beginning to 9 x 10^8 cells per m^3 at the end (after ~ 40d). Depending on the exhaust air flow rate, a number of > 10^{10} microbial cells were emitted from the broiler shed per second. The most abundant sequences (60%) of 16S rRNA gene clone libraries could be assigned to the genus *Staphylococcus.* Altogether, 28 different bacterial species within 11 different bacterial genera were detected. The most frequently detected sequences are those most closely related to bacteria of the risk group 1. However, sequences most closely related to *Staphylococcus saprophyticus, Aerococcus viridans, Enterococcus hirae, E. faecium* and *Escherichia* spp. indicated the emission of risk group 2 bacteria, as well. Between 4 and 11% of sequences in 8 of 12 investigated clone libraries could be assigned to the genus Jeotgalicoccus. This high abundance was verified by a Jeotgalicoccus specific quantitative real-time PCR (Martin et al., 2010b). A remainder of approximately 21% from all analysed sequences was related to uncultured bacteria. This study confirmed that broiler sheds are a potential source for microbial air pollution. The most abundant bacterial genus

was Staphylococcus. But the cloning and real time PCR approaches of this study revealed that Jeotgalicoccus may be a potential detection target for emission and ambient air measurements from broiler sheds.

CONCLUSION: In regard to increasing poultry meat production, both from an ecological and medical perspective, the environmental impact of emissions from poultry houses should be considered in further investigations.

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GREENHOUSE GAS BUDGET OF AN ORGANIC BROILER PRODUCTION SYSTEM IN FRANCE

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ABSTRACT: This paper presents the greenhouse gas (GHG) budget of an organic broiler production system in France, composed of a broiler house and an outdoor run. The study was conducted over 1 year on an experimental farm. In the broiler house, emissions of N_2O and CH_4 were measured using photo-acoustic infrared spectrometry and air flow rates were estimated using SF6 as tracer gas. On the outdoor run, N_2O and CH_4 fluxes were measured using static chambers. Spatial and temporal gap-filling methods were used to provide annual estimates of emissions. In the broiler house, CH_4 and N_2O annual emissions from manure represented about 49 and 71 g CO_2-equivalents (CO_2-eq.)/kg live weight (LW), while non-biotic CO_2 emissions (heating) represented about 68 g CO_2-eq./kg LW, suggesting that manure accounted for about 65% of total indoor CO_2-eq. emissions. On the outdoor run, N_2O emissions were estimated to 86 g CO_2-eq./kg LW, while CH_4 emissions were found negligible (-1 g CO_2-eq./kg LW). However, long-term C sequestration on the outdoor run should be investigated since measured short-term variations in soil organic carbon suggested that the run could display a sink activity and thus compensate for a portion of GHG emissions.

Keywords: greenhouse gas, organic farming, nitrous oxide, methane, poultry

INTRODUCTION: Climate change is one of the most challenging environmental issues of the 21st century and solutions must be found to mitigate greenhouse gas (GHG) emissions on a global scale (IPCC, 2007). However, few data concerning GHG emissions from poultry rearing systems are available and uncertainties on emission factors are high (Meda et al., 2011). This lack of knowledge is even greater for alternative, less intensive rearing systems, which provide an outdoor access to the animals (free-range and/or organic farming). Estimates of GHG emissions from these systems are needed from an inventory perspective, but to our knowledge there is no available study concerning GHG emissions from organic poultry. In this paper, we present measurements of GHG (N_2O, CH_4 and non-biotic CO_2) fluxes from a French organic broiler production system during one year. The study was conducted on two broiler batches, reared in contrasted seasons, and the measurements were used to provide an annual budget of the organic broiler production system.

1. MATERIAL AND METHODS:

1.1. Study site and organic broiler production system: The study occurred on the experimental facility of the French National Institute for Agricultural Research (INRA) at Le Magneraud (Charente-Maritime). Five broiler batches were reared consecutively on the site between March 2009 and November 2010. The GHG flux measurements presented in this paper were performed during two batches only (batches 3 and 5). Batch 3 (or WS) was studied from December 2009 to May 2010,

while batch 5 (or SA) was studied from August 2011 to December 2010. During each batch, approximately 800 slow-growing strain broilers were reared in a 75m^2 broiler house with straw bedding. After 4-5 weeks, two 2 m pop-holes were continuously open and allowed the animals an unlimited access to the outdoor run, a 2350m² grassland.

1.2. Emissions in the broiler house: Within the broiler house, monitoring of gaseous emissions was performed continuously over 3 periods of 20, 15 and 21 days and 30, 14 and 30 days, respectively, for WS and SA batches. Hourly emissions (*E*, g/h) of GHG were calculated by crossing concentration gradients (g/m^3) between indoor air (C_{indoor}) and outdoor air ($C_{outdoor}$) with housing ventilation (Q, m^3/h) corrected by indoor air density ρ_{indoor}, according to Equation 1:

$$E = Q \times \rho_{indoor} \times (C_{indoor} - C_{outdoor}) \quad (1)$$

Housing ventilation rates were measured using the tracing method (Phillips et al., 2001) with SF_6. SF_6 was injected with a known rate within a mixing shaft. The variations of indoor and outdoor concentrations were used to calculate the housing ventilation. N_2O, CO_2, CH_4, and SF_6 concentrations were measured continuously using infrared photoacoustic spectrometry, with a gas analyser coupled with a sampler-dozer (INNOVA 1312 and 1303). Two sampling channels were placed outside, and four within the broiler house. Outdoor and indoor temperature and relative humidity in the house were continuously measured during the rearing period. Air samples were pumped by the sampler-dozer using insulated and heated PTFE tubes to avoid condensation. Emissions were cumulated from chick arrival to litter removal and expressed as per kg of live weight (LW) produced.

1.3. Emissions on the outdoor run: CH_4 and N_2O fluxes on the outdoor run were measured using static chambers (Smith et al., 1995). Sixteen chambers were placed on the outdoor run, 8 of which were placed within the first 15 m in front of the broiler house, since broilers are preferentially in this zone. Moreover, 3 chambers were used as control chambers outside the outdoor run. At the start of each measurement period, the chambers were covered with a removable lid equipped with a septum. Four air samples were taken (at 0, 10, 20 and 30 min) and injected into evacuated vials closed with leak-free septa before analysis using gas chromatography. Gas fluxes for each chamber were calculated from the slope of the linear regression of concentration over time. Soil temperature and soil water content at -5 cm were also measured during the study.

For each measurement day, the spatial integration of GHG fluxes was performed using geostatistical methods. Gridded fluxes were totaled to provide spatial integrals for each GHG and each measurement day (Meda et al., 2012). Moreover, to fill in the gaps between two measurement days, gap-filling methods were used. A mechanistic gap-filling function between N_2O fluxes and assumed control variables (soil temperature and soil water content) was developed (Meda et al., 2012), whereas linear interpolation was used for CH_4 fluxes. Temporal integrals were then calculated by totalling actual measurement-based spatial flux integrals for each measurement day and gap-filled fluxes in between.

2. RESULTS AND DISCUSSION:

2.1. GHG emissions of the broiler production system: Estimates of indoor and outdoor total emissions of N_2O and CH_4 are given in Table 1. Non-biotic CO_2

emissions are also given in Table 1. These emissions correspond to propane combustion (propane consumption was recorded during the study) used to heat the broiler house during the first weeks of age of the young animals.

Table 1. Indoor and outdoor GHG emissions of the broiler production system measured during two batches and extrapolated for the year 2010.

	WS batch	SA batch	Year 2010
Indoor emissions			
g N_2O (g/kg LW)	598 (0.40)	135 (0.09)	1124 (0.24)
g CH_4 (g/kg LW)	2999 (2.00)	3214 (2.03)	9366 (1.98)
kg non-biotic CO_2 (kg/kg LW)*	158 (0.11)	57 (0.04)	325 (0.07)
Outdoor emissions			
g N_2O (g/kg LW)	337 (0.23)	747 (0.47)	1358 (0.29)
g CH_4 (g/kg LW)	-114 (-0.08)	16 (0.01)	-174 (-0.04)

*Emissions due to the combustion of propane to heat the broiler house

In the broiler house, N_2O emissions were higher during winter/spring (WS) than in summer/autumn (SA), whereas on the outdoor run they were higher during the SA batch than during the WS batch. This can be explained by broilers spending more time on the outdoor run during the SA batch, and thus excreting more N on the run compared to the WS batch. Yet, annual estimates for indoor and outdoor emissions were of the same order of magnitude (0.24 and 0.29 g N_2O /kg LW, respectively).

Concerning CH_4, it appears that broiler house manure is the main emission source, since the outdoor run emitted few CH_4, and even seemed to act like a small carbon sink. Moreover, indoor CH_4 emissions are not affected by the season or the time broilers spend in the house since the emission factor remains close to 2 g/kg LW. On the outdoor run the grassland acted like a small sink (-0.04 g/kg LW) during the year 2010. Yet, this sink only compensated for 2% of CH_4 indoor emissions.

2.2. Annual CO_2-equivalent budget of the broiler production system: The annual estimates of GHG emissions (Table 1) were converted into CO_2-equivalents (CO_2-eq.) by using their global warming potential (298, 25 and 1, respectively, for N_2O, CH_4 and CO_2 given by the IPCC (2007). Results are presented in Figure 1. Over the year 2010, average CO_2-eq. emissions were estimated at 273 g/kg LW, which is consistent with values given by Seguin et al. (2011). Indoor GHG emissions contributed to 26, 25 and 18% of total emissions, respectively, for N_2O, non-biotic CO_2 and CH_4 emissions. On the outdoor run, N_2O emissions are the main source of GHG (31% of total CO_2-eq.) and the small carbon sink due to CH_4 consumption compensated for less than 1% of CO_2-eq. due to N_2O. However, the outdoor run could act as a potential carbon sink and could thus compensate for a larger portion of GHG emissions through carbon sequestration. Soil samples (before the first batch and after the last batch) showed a significant increase in soil organic carbon (SOC) content (Meda et al., 2012). However, we only measured short-term variations of SOC content and long-term variations should be investigated through long-term measurements.

It must be stressed that the GHG budget of this broiler production system does not include indirect emissions such as those due to feed production. Based on data from Seguin et al. (2012) for the impact of one kg of organic feed produced (about 550 g

CO_2-eq./kg feed), we estimated that the emission of GHG represented about 1.8 kg CO_2-eq./kg LW produced, confirming that the feed production stage is much more critical (in terms of CO_2-eq. emissions) than the farm production stage.

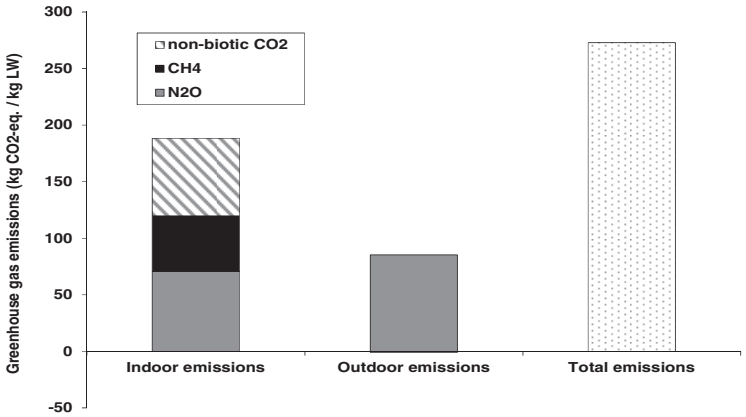

Figure 1. Annual CO_2-equivalent budget of a French organic broiler production system.

CONCLUSION: This study provides initial data on GHG emissions from a broiler production system associating both a broiler house with manure and an outdoor run with droppings interacting with soil and vegetation. We demonstrated that indoor GHG emissions (in CO_2-eq.) represented about 70% of total emissions from the production system. However, the role of the outdoor run in the budget was only investigated through estimating positive flux (i.e. emissions), and the outdoor run could possess net sink activity (carbon sequestration). Total NH_3 emissions should also be quantified given the potential impacts associated with NH_3 deposition downwind from the source.

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AERIAL POLLUTANT EMISSIONS FROM HIGH-RISE LAYER HEN HOUSES WITH TWO-YEAR CONTINUOUS MONITORING

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ABSTRACT: This paper summarises results of a 2-year continuous monitoring of ammonia (NH_3), carbon dioxide (CO_2), hydrogen sulphide (H_2S), and particulate matter (PM_{10}) emissions from two 218,000-hen high-rise layer houses (H-A and H-B) in the state of Indiana, USA. Gaseous pollutant concentrations were measured with two gas analyzers and PM_{10} concentrations were measured with three Tapered Element Oscillating Microbalances. Ventilation fans were continuously monitored with fan control relays, vibration sensors, and impeller anemometers. Valid data days (days with more than 18 h, or 75%, of valid data) during the 2-year study in emission per house (mass d^{-1} $house^{-1}$) and emission per day per animal unit (mass d^{-1} AU^{-1}) for the four pollutants ranged from 279 to 542 d for H-A and from 286 to 529 d for H-B. Average daily mean emissions were 357±137 g AU^{-1} (mean ± standard deviation) from H-A and 386±149 g AU^{-1} from H-B for NH_3; 508±229 mg AU^{-1} from H-A and 462±318 mg AU^{-1} from H-B for H_2S; 26.2±4.2 kg AU^{-1} from H-A and 26.9±6.0 kg AU^{-1} from H-B for CO_2; and 6.00±5.27 g AU^{-1} from H-A and 8.03±7.2 g AU^{-1} from H-B for PM_{10}. Emissions between the houses were statistically different ($P<0.05$) for NH_3 and PM_{10}. Significant annual emission variations were exhibited for all four pollutants ($P<0.01$).

Keywords: air quality, NH_3, CO_2, H_2S, particulate matter, poultry, house

INTRODUCTION: Emissions of ammonia (NH_3), hydrogen sulphide (H_2S), carbon dioxide (CO_2), and particulate matter (PM) from poultry houses are well-known environmental concerns. Long-term (> 6 months) and continuous (or high frequency) monitoring that can reveal seasonal and diurnal variations is needed to obtain in-depth knowledge about the emissions of these pollutants. Emission monitoring was conducted for two years in four layer hen houses at a commercial egg production facility in Indiana, USA as part of the National Air Emission Monitoring Study (NAEMS) using state-of-the-science methodologies and technologies (Heber et al., 2008). The NAEMS' layer hen sites in California (Lin et al., 2012) and North Carolina (Wang-Li et al., 2012) each consisted of monitoring in two commercial high-rise houses. The study in Indiana consisted of two high-rise and two manure-belt houses and produced the largest agricultural air quality dataset from a single layer farm. The objective of this paper is to summarise the measured NH_3, H_2S, CO_2, and PM_{10} emissions from the Indiana high-rise houses.

1. MATERIAL AND METHODS: In the two high-rise houses (H-A and H-B), hens were confined in ten rows of five-tier A-frame cages on the second or upper floor (Figure 1). Manure dropped off slanted boards beneath the cages directly into the manure pit or first floor. Ventilation air entered the cage level from the attic. There were 110 belt-driven ventilation fans of 122-cm diameter (Model AT481Z1CP,

Aerotech Inc., Mason, MI, USA) distributed along the west and east sidewalls in each house and operated in 13 stages. Ten of the 110 fans were variable-speed and constituted the first stage ventilation. The other 100 fans were single-speed and assigned to the remaining 12 stages. Fifty circulation fans in the manure pit assisted in drying the manure. An on-farm instrument shelter (OFIS) housed instruments, sensors, an on-site computer system, calibration gas cylinders, and tools, and provided office space at the monitoring site.

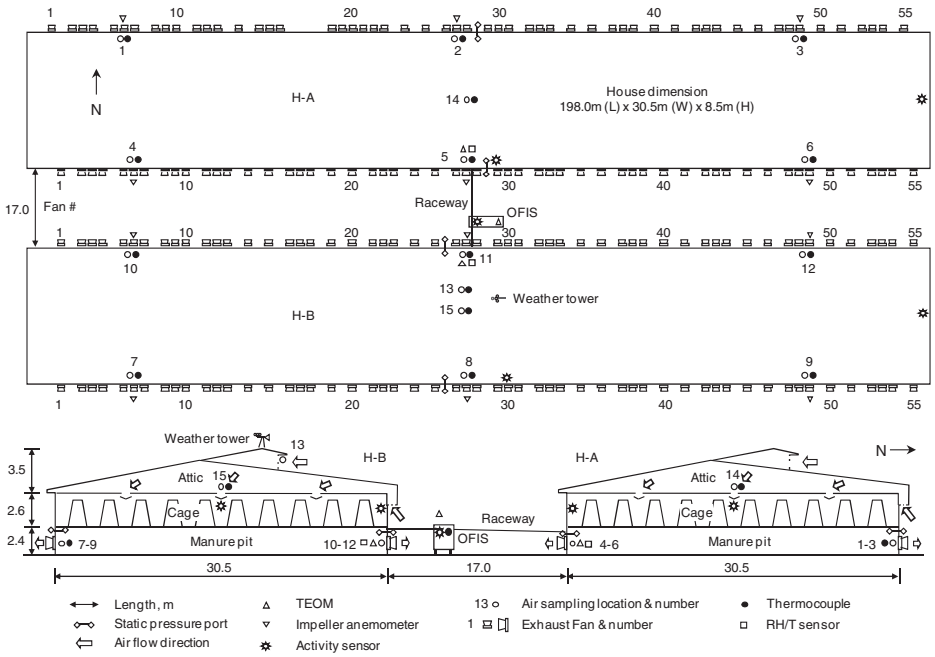

Figure 1. Floor plan (top) and cross-sectional east-side view (bottom) of the houses with approximate measurement and sampling locations.

1.1. Gaseous Pollutant Monitoring: Air samples for continuous gas concentration measurement were collected from multiple gas sampling probes with a custom-designed gas sampling system (GSS). All sampling probes were connected to the GSS with Teflon tubing. There were a total of 15 gas sampling locations (GSL) in the two houses. Twelve of these were at the inlets of first-stage pit ventilation fans. One GSL (#13) sampled outdoor air at H-B roof top. Two others (#14 and #15) were set up for house inlet air in the attics. The sampling durations were 20 min for the first air inlet location and 10 min for all other locations. Two gas analyzers measured gas concentrations as the GSS sequenced through all the GSL. Concentrations of NH_3 and CO_2 in the sampling air were measured with one multi-gas photoacoustic monitor (Innova Model 1412, LumaSense Technologies, Ballerup, Denmark). Concentrations of H2S were measured with a H2S analyzer that consisted of a Model 43 analyzer and a Model 340 converter (Thermo Electron Co., Franklin, MA, USA).

1.2. Particulate Matter Monitoring: Tapered Element Oscillating Microbalance (TEOM Model 1400a, Thermo Fisher Scientific) was used to continuously sample and measure PM_{10} concentrations. Two TEOMs were set up at about 1 m from the inlets of two selected first-stage fans, one at south-wall fan 27 in H-A and another at

north-wall fan 27 in H-B. The outdoor air was sampled at 1.2 m above the OFIS roof with a third TEOM.

1.3. Ventilation Monitoring: House ventilation was monitored with several different techniques. All the stage control relays of ventilation fans were monitored. Fans were also individually and continuously monitored either by vibration sensors (Model OSU-06, Ohio State University, Columbus, OH, USA) (Chen et al., 2010), magnetic proximity sensors (Model MP100701, Cherry Co., Pleasant Prairie, WI, USA), and/or impeller anemometers (Model 27106RS, R.M. Young Company, Traverse City, MI, USA). House differential pressures across east and west walls, which were used to calculate fan airflow rates, were continuously measured using pressure sensors (Model 260, Setra Systems, Inc., Boxborough, MA, USA) with a measurement range from -100 to +100 Pa.

2. RESULTS AND DISCUSSION: There were 217,832±1624 and 218,254±1549 hens (mean±95% confidence interval) in H-A and H-B during the two-year study, respectively. The numbers of hens were not statistically different (P>0.05) between the houses. House ventilation rates were 185±13.2 and 202±14.5 m^3 s^{-1} for H-A and H-B, respectively (P>0.05). Table 1 summarises the pollutant emission rates with two units.

Table 1. Results of air pollutant emissions from the two high-rise houses.

Parameter	Total emission per house			Emission per animal unit (AU)		
	H-A	H-B	Unit	H-A	H-B	Unit
Ammonia						
2-yr valid days[a]	525	512	d	520	512	d
1st yr mean[b]	248±83	297±90	kg d^{-1}	384±126	456±142	g d^{-1}
2nd yr mean[b]	200±82	203±81	kg d^{-1}	333±142	318±121	g d^{-1}
2-yr mean[b]	223±86	249±97	kg d^{-1}	357±137	386±149	g d^{-1}
2-yr mean[c]	223±7	249±8	kg d^{-1}	357±12	386±13	g d^{-1}
Hydrogen sulphide						
2-yr valid days[a]	284	286	d	279	286	d
1st yr mean[b]	372±150	428±234	g d^{-1}	563±219	645±345	mg d^{-1}
2nd yr mean[b]	279±152	184±99	g d^{-1}	461±227	298±169	mg d^{-1}
2-yr mean[b]	321±158	299±214	g d^{-1}	508±229	462±318	mg d^{-1}
2-yr mean[c]	321±18	299±25	g d^{-1}	508±27	462±37	mg d^{-1}
Carbon dioxide						
2-yr valid days[a]	542	529	d	537	524	d
1st yr mean[b]	16,957±2681	18,064±4712	kg d^{-1}	26.2±4.7	28.8±7.2	kg d^{-1}
2nd yr mean[b]	15,808±2898	15,730±2281	kg d^{-1}	26.1±3.5	24.7±3.3	kg d^{-1}
2-yr mean[b]	16,402±2846	16,970±3948	kg d^{-1}	26.2±4.2	26.9±6.0	kg d^{-1}
2-yr mean[c]	16,402±240	16,970±336	kg d^{-1}	26.2±0.4	26.9±0.5	kg d^{-1}
PM_{10}						
2-yr valid days[a]	411	403	d	407	399	d
1st yr mean[b]	2478±2313	4018±3933	g d^{-1}	3.96±3.8	6.5±7.45	g d^{-1}
2nd yr mean[b]	5051±3495	5919±3795	g d^{-1}	8.35±5.74	9.66±6.54	g d^{-1}
2-yr mean[b]	3687±3197	4934±3982	g d^{-1}	6.00±5.27	8.03±7.2	g d^{-1}
2-yr mean[c]	3687±309	4934±389	g d^{-1}	6.00±0.51	8.03±0.71	g d^{-1}

[a] Days with >18 hr of valid data daily; [b] Mean±standard deviation; [c] Mean±95% confidence interval.

Valid data days (days with more than 18 h, or 75%, of valid data) during the 2-year study in emission per house (mass d^{-1} $house^{-1}$) and emission per day per animal unit (mass d^{-1} AU^{-1}) for different pollutants ranged from 279 to 542 d for H-A and from 286 to 529 d for H-B. The fewer valid days for H_2S and PM_{10} were due to technical

problems related to the analyzers. The valid data days for emissions per house included empty-house days between flocks of birds.

Average daily mean (ADM) NH_3 emissions were 358±12 and 386±13 g AU^{-1} (mean ± 95% confidence interval) from H-A and H-B, respectively, and were statistically different ($P<0.05$). Emissions of ADM H_2S from H-A and H-B were 508±27 and 462±37 mg AU^{-1}, respectively ($P>0.05$). Emissions of ADM CO_2 were 26.2±0.4 kg AU^{-1} from H-A and 26.9±0.5 kg AU^{-1} from H-B ($P>0.05$), and ADM PM_{10} emissions were 6.00±0.51 g AU^{-1} from H-A and 8.03±0.71 g AU^{-1} from H-B ($P<0.05$). This study also demonstrated significant variations in annual house emissions from both houses between the first and second years of monitoring for all four pollutants ($P<0.01$).

CONCLUSION: (1) The long-term study generated one of the most comprehensive emission datasets for high-rise layer hen houses in the USA. It revealed annual emission variations for all studied pollutants. (2) Emission variations between the two identical houses for certain pollutants, especially NH_3, imply that there were yet unknown factors affecting pollutant production and emissions. (3) Future in-depth data analysis and data mining could generate more knowledge about air pollution from layer hen houses to benefit the egg industry and environmental protection. (4) Technical failures of some instruments caused the loss of data and lowered emission data completeness. Lessons learnt from this and other issues, and experience gained in this study will help to improve the quality of future emission monitoring.

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GREENHOUSE GAS EMISSIONS IN THE TREATMENT OF LAYING HEN FARM RESIDUES BY IN-VESSEL COMPOSTING WITH FORCED AERATION

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ABSTRACT: A biological reactor was developed for the treatment of laying hen farm residues through in- vessel composting with forced aeration. The objective of this study was to evaluate greenhouse gas (GHG: CO_2, CH_4, N_2O) and ammonia (NH_3) emissions during the composting of a mixture of chicken manure (64.4%), discarded eggs (1.4%), dead chickens (0.9%), slaughterhouse centrifuged sludge (3.1%) and sawdust (30.2%). The reactor was loaded with 5,788 and 5,842 kg of the mixture for two 7-day trials with and without the use of a biological inoculant (Humidibiol). Afterwards, compost was removed for maturation outside the bioreactor during a 21-day period. Gaseous emissions of CO_2, CH_4, N_2O, and NH_3 were measured by infrared photoacoustic spectroscopy using an INNOVA 1412 trace gas analyzer (Lumasense Technologies, Denmark). Dry matter (DM), total organic carbon (TOC), total kjeldahl nitrogen (TKN), phosphorous (P) and pH content in the mixture were determined at the beginning and the end of the trials (thermophilic composting phase) and after compost maturation. Biomass temperature inside the reactor was maintained above 55°C in both trials. C losses measured as CO_2 and CH_4 during in-vessel composting represented 12.3 and 11.1% of the original C content of the mixture, with and without inoculation, respectively. Measured $N\text{-}NH_3$ + $N\text{-}N_2O$ losses represented 22.8 and 25.8% of the original N content of the mixture, with and without inoculation, respectively. No significant differences were observed in the patterns of GHG and ammonia emissions due to the use of the biological inoculant.
$C\text{-}CH_4$ represented just 0.58% of the measured gaseous C losses in both trials, while $C\text{-}CO_2$ losses accounted for 99.42%. The high CH_4:CO_2 emission ratio (1:170) demonstrated that O2 saturation inside the bioreactor was high during the entire thermophilic composting phase, inhibiting anaerobic methanogenic microorganisms.
$N\text{-}N_2O$ represented just 0.44% of the measured gaseous N losses in both trials, while $N\text{-}NH_3$ losses accounted for 99.56%. Considering the global warming potential (GWP) of each GHG, 422.3 kg of CO_2eq were emitted during composting, on average, in both trials. CO_2 emissions accounted for 81.7% of total CO_2eq emission, while CH_4 and N_2O represented 3.6 and 14.6%, respectively. Mitigation of CH_4, and especially N_2O, emissions during composting is critical due to the high GPW of these gases.

Keywords: accelerated composting, poultry, GHG, CO_2, CH_4, N_2O

INTRODUCTION: The main characteristic of the composting process is the biological degradation of organic matter by aerobic microorganisms, which promotes heating of the biomass that removes pathogenic microorganisms and evaporates the water (Paillat et al., 2005). Composting has been recommended for the treatment of caged layers' waste because it enables nutrient recycling, adds economic value to wastes and reduces the risk of environmental contamination (Aubert, 2006); (Tiquia and Tam, 2002). A bioreactor with forced aeration was developed with the objective

to accelerate the degradation of organic waste from laying hen farms. The equipment helps maintain a constant level of oxygen and promotes faster degradation and stabilization of organic matter. The objective of this study was to evaluate the accelerated composting process by measuring gas emissions (CO_2, CH_4, N_2O and NH_3) and to calculate the mass balance of the process.

1. MATERIALS AND METHODS: The study was conducted on a commercial farm in the city of Erexim / RS. Two experiments were performed during 14 days (seven days each). The bioreactor was loaded with 5,788 kg of a mixture composed of laying hen manure, sawdust, rotten eggs and dead birds. In Experiment 2, the biological inoculant Humidibiol was added to the mixture. The bioreactor operates in a batch system, and both experiments were conducted in two phases. The first (thermophilic) occurs inside the bioreactor and lasts 7 days. The second phase occurs in external piles rotated weekly (mesophilic) during 21 days. Gaseous emissions of the thermophilic phase were always measured during two hours in the afternoon. Gas concentration (ppm) was measured in intervals of one minute in the entrance and exit of the air in the bioreactor using the Photoacoustic Gas Monitor INNOVA 1412. The gas flow was determined according to the methodology proposed by Robin et al. (2006) and Fukumoto et al. (2003). The daily evaluated parameters were: temperature of the biomass in the reactor at 5 different points, temperature and humidity of outside air, the dry matter (DM), total organic carbon (TOC), total kjeldahl nitrogen (TKN), phosphorus (P), Mineral Matter (MM) and pH according to the methodology of the Association of Official Analytical Chemists (1995). The mass balance was calculated from the difference between the amount of C and N contained in the mixture loaded into the bioreactor. Those contained in the biomass resulted from the first stage of the process, and this difference was considered the mass lost, and was compared to the gaseous emissions of these elements

2. RESULTS AND DISCUSSION: The temperatures recorded for Experiments 1 and 2 showed that the behavior presented by these two issues were significantly different. In Experiment 1 the biomass temperature reached 50°C on the second day, while in Experiment 2 this temperature was only achieved on the fourth day; it also takes longer to reach the maximum temperature (60°C). Nevertheless, the moisture of the biomass at the beginning of the process was 2% higher in Experiment 2 compared to Experiment 1. (Figure 1) shows the emission of C-CO_2 and C-CH_4 in Experiments 1 and 2. These emission flows show the changes that might have been caused by the use of the biological activator. In Experiment 1, CO_2 emissions were higher in the beginning of the process and continuously decreased over several days until reaching a daily emission of 1.2 kg of CO_2. In Experiment 2, the daily CO_2 emission at the end of the first phase was 0.8 kg. The amount of total carbon emitted as C-CO_2 in Experiments 1 and 2 was 122.38 kg and 88.7 kg, respectively. Additionally, the amount emitted as C-CH_4 was about 0.50 kg and 0.34 kg for Experiments 1 and 2, respectively, which shows that 99.6% of the C mineralization occurred by aerobic process (predominance of the generation of CO_2). During Experiment 2, the pH varied from 8.3 to 9.2, with a slight difference in alkalinity compared to Experiment 1. At the beginning of the process in Experiment 1, the flows of N-N_2O are correlated with the flows of N-NH_3. The higher NH_3 emission inhibited the formation of nitrate and consequently the N_2O emission. In Experiment 2 the flow of N-NH_3 was lower at the beginning of the process, which corresponded to the period of highest N-N_2O cumulative flow (Figure 2). The amount of N emitted as N_2O during Experiments 1 and 2 was 0.08 kg and 0.05 kg, respectively, which corresponds to 0.44% and 0.38%

of total N emissions. The N-NH_3 loss during Experiments 1 and 2 was about 13 and 12 kg, respectively, which corresponds to 99% of total N emissions. This high loss of N as NH_3 can be explained by high pH values and low C/N of the biomass at the beginning of the process. Furthermore, the C/N increases as the process progresses, in the same way that (Aubert, 2006); (Tiquia and Tam, 2002) have observed in previous work with forced aerated composting of chicken manure. According to these authors, this C/N behavior occurs due to high N-NH_3 losses. According to mass balance, there is a mineral amount concentration, as was observed by (Tiquia and Tam, 2002). Furthermore, the amount of N and C entering the system was higher in Experiment 1, also showing a greater loss of these elements as well as mass. The mass loss was 30.5% in Experiment 1 and 22.8% in Experiment 2. (Aubert, 2006) and (Robin et al., 2001) found natural mass loss between 40 and 50% in chicken manure composting.

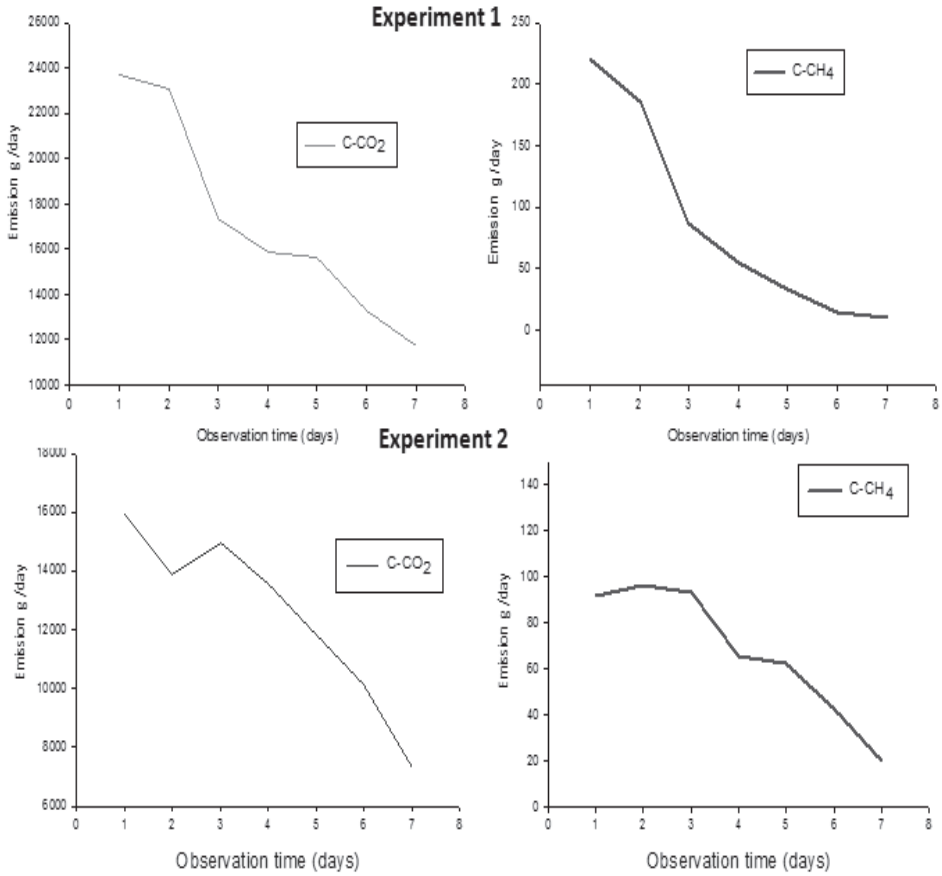

Figure 1. Emissions of C-CO_2 and C-CH_4 during Experiments 1 and 2.

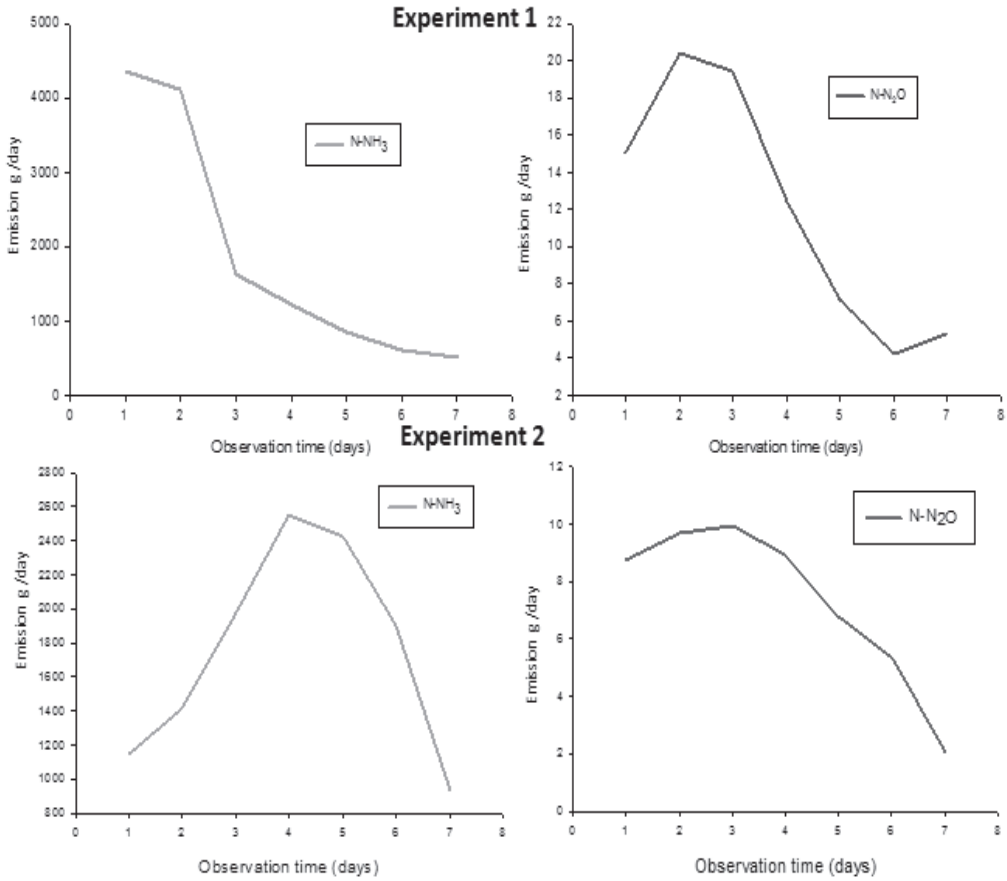

Figure 2. Emission of N-NH_3 and N-N_2O during Experiments 1 and 2.

Table 1 shows the mass balance observed in Experiments 1 and 2. As expected, the loss of phosphorus (P) was low (5-7%); however, the evaluation of this element is important because it is used to gauge the mass balance and the representativeness of the biomass sampling. The losses observed (Table 1) were 9.9% and 2.8% for DM and 49.4% and 19.6% for TKN in Experiments 1 and 2, respectively. These results are in agreement with (Aubert, 2006), who found losses between 13.6% and 5.8% for DM.

Table 1. Mass balance of the first phase of composting (Experiment 1 and Experiment 2), Mass (kg), DM (kg), OM (kg), MM (kg) N (kg), C (kg) and P (kg).

Experiment 1							
	Mass	DM	OM	MM	N	C	P
Entrance	5788.0	2174.55	1937.59	236.96	57.75	858.80	32.03
Exit	4021.3	1959.22	1686.5	272.72	29.18	761.65	30.36
Loss	1766.7	215.33	251.09	-35.76	28.57	97.15	1.67
*Measure Emissions	-	-	-	-	13.15	122.38	-
% gases/Loss	-	-	-	-	46.03	-25.97	-
% mass/Loss	30.5	9.91	12.9	-15.0	49.47	11.31	5.2
Experiment 2							
Entrance	5788.0	2084.84	1824.9	259.9	49.20	770.9	29.10
Exit	4467.2	2027.25	1689.5	337.7	39.54	712.5	27.08
Loss	1320.8	57.59	135.4	-77.8	9.66	58.4	2.01
*Measure Emissions	-	-	-	-	12.7	88.7	-
% gases/Loss					-31.46	-51.8	
% mass/Loss	22.82	2.76	7.42	-29.93	19.63	7.57	6.91

*GASES ($N\text{-}N_2O + N\text{-}NH_3$) AND ($C\text{-}CO_2 + C\text{-}CH_4$)

CONCLUSION: Accelerated composting is an efficient technique for the treatment of laying hen manure and produces organic compost with high nutrient concentration. The use of a biological inoculant reduces nitrogen loss and results in compost with higher nitrogen content. The methodology employed to measure gas flow from accelerated composting presented satisfactory results, as indicated by mass balance.

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GREENHOUSE GAS EMISSIONS ON THE TREATMENT OF SWINE SLURRY BY COMPOSTING

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ABSTRACT: The treatment of swine manure through composting is seen as an alternative to minimize environmental impact and improve nutrient recycling. However, the degradation of organic matter during the composting process promotes greenhouse gas emissions (GHG: CO_2, CH_4, N_2O), NH_3 and water vapor. The objective of this study was to measure the flux of these gases to perform the mass balance (DM, TN, C and P) of composting piles. Three compost piles (3 m^3, initial mass 2.935 kg of sawdust and slurry) were mounted inside PVC tunnels with controlled ventilation (flow 1.526 m^3/h). We evaluated temperatures and humidity (Datalogger TESTO 174H) inside and outside the tunnels and inside the biomass (TESTO Mod. 926, Type T), performed physical-chemical analysis of compost and measured GHG, NH_3 and water vapor emissions every 4 min through infrared photoacoustic spectroscopy (INNOVA 1412). The average temperature observed in the biomass during composting was 45.53 ± 5.48ºC. The average H_2O balance error (between input and output) recorded was 5.52%. Gaseous losses of N-NH_3 and N-N_2O totaled 1.21 kg, representing 10.4% of the original 11.63 kg of N applied in the compost piles. NH_3 represented 78% of measured total N gaseous losses (NH_3+N_2O). The total C emitted as CH_4 and CO_2 gases totaled 80.96 kg, representing 40.2% of the original 201.28 kg of TOC in compost piles (sawdust+slurry). CO_2 emission accounted for 97% of total C losses. Considering the global warming potential (GWP) of each GHG, 615.3 kg of CO_2eq were emitted during composting. CO_2 emissions accounted for 46.8% of total CO_2eq emission, while CH_4 and N_2O represented 11.1 and 42.2%, respectively. Mitigation of CH_4, and especially N_2O emissions, during composting is critical due to the higher GPW of these gases. The presence of pathogenic microorganisms (Escherichia coli and coliform bacteria) was observed in the input slurry, but those microorganisms were not detected in the final compost. It was possible to accurately measure and verify gas emissions with the association of direct measurements and mass balance.

Keywords: swine manure, manure treatment, global warming potential, carbon dioxide, methane, nitrous oxide, ammonia

INTRODUCTION: Residues from animal production systems are responsible for greenhouse gas (GHG) emissions and water and soil contamination in Southern Brazil (Sardá et al., 2010). These residues have an important role in ammonium (NH_3) and methane (CH_4) emissions to the atmosphere (IPCC, 1995). Composting has been appointed as an alternative to minimize the environmental impact of the animal production residue management allowing nutrient recycling (Oliveira and Higarashi, 2006). However, during organic matter degradation, other gases could be emitted beyond CH_4 and NH_3, such as nitrous oxide (N_2O) (Paillat et al. 2005). The reason for these emissions is not completely understood, mainly in Brazil, where the composting process developed by Oliveira and Higarashi (2006) is currently widely adopted for the treatment of swine slurry. The objective of this study was to determine GHG

($N\text{-}N_2O$, $C\text{-}CH_4$ and $C\text{-}CO_2$) and $N\text{-}NH_3$ fluxes and to perform mass balance in the swine slurry composting process in Southern Brazil.

1. METHODS: Three tunnels (12 m^3) with controlled aeration were built and covered with PVC film. Inside each tunnel 2.52 m^3 static composting piles were mounted in wooden boxes. Composting was divided into two phases. The first was the absorption phase where swine slurry was applied to the piles and was considered a period with high carbon/nitrogen ratio (C/N) in the compost piles. During this first phase swine slurry was applied to the piles once a week. The pile was rotated 3 days after every slurry application or when the composting pile moisture was over 80%. The second phase was the maturation of the biomass, when slurry was no longer applied to the composting piles. During this phase, the composting piles were rotated once a week. Gas emissions were monitored only in the absorption phase when GHG and NH_3 emissions are expected to be higher (Paillat et al., 2005). The absorption phase lasted 35 days and 2,600 L of swine slurry was incorporated into compost piles in 7 applications. Each application was performed observing the maximum incorporation rate (3 L/kg of sawdust) (Oliveira and Higarashi, 2006) to avoid slurry percolation and runoff from composting piles. Gas emissions were calculated based on the air flux inside each tunnel determined by a hot wire anemometer (TESTO 435), and gas concentrations in the tunnels' inlets and outlets every 4 minutes by trace gas analyzer INNOVA 1412 (infrared photoacoustic spectroscopy),

following the equation proposed by Robin et al. (2006):

$$\phi = Q_{ar} \times \rho_i \times (C_i^m - C_e^m) \qquad \text{Equation (1)}$$

Where, φ is the gas emission rate (g/h in dry air); Q_{ar} is the air flow (m^3/h); ρ_i is the conversion factor from air flow volume to air mass flow, allowing the implementation of mass and energy conservation laws (m^3/h to kg/h). The ideal gas law was used considering the air temperature as 20ºC for the conversion of the gas using equation 2:

$$C_i^m = C_i^v \times \frac{M_m}{V_m} \times \frac{M_m}{M_{mol}} \qquad \text{Equation (2)}$$

Where, C^m_i is the equivalent concentration of C and N in gases (mg/m^3), measured at time *i* ($C\text{-}CH_4$; $C\text{-}CO_2$; $N\text{-}NH_3$; $N\text{-}N_2O$); C^v_i is the concentration of the measured gas (ppmv); M_m is the equivalent molecular mass of C and N in the considered gas (ie. CH_4=12, NH_3=14, N_2O=28 g de N.mol^{-1}); M_{mol} is the molar mass in each gas molecule (CO_2=44, CH_4=16, NH_3=17). V_m is molar volume (L/mol) corresponding to the molecular mass of a perfect gas at pressure (P) and temperature of 20°C (T). Beyond gas emissions, other parameters were evaluated, such as air temperature and moisture inside and outside the tunnels. Compost was submitted to physical-chemical analysis. Mass balance was performed based on C and N inputs in the system through swine slurry and sawdust, along with the concentration of these elements of the compost biomass. The differences in C and N mass were considered losses of these elements as gaseous emissions and were compared to measured $C\text{-}CH_4$, $C\text{-}CO_2$, $N\text{-}NH_3$, and $N\text{-}N_2O$ emissions. Phosphorus balance and water concentration in the compost pile were used to estimate errors on mass balance, considering the used methodology. The characteristics of sawdust and swine slurry used in the experiment are shown in Table 1.

Table 1.Physical-chemical characteristics of materials used in the composting ($g.kg^{-1}$).

Material	Dry matter (%)	Tot. Nitrogen	Organic Carbon	Phosphorus (PO_4)
Swine slurry	3,8 – 36,4	2,3 – 6,7	13,3 – 57,1	0,8 – 3,9
Sawdust	89,31	2,17	537	0,20

Sawdust substrate granulometry was characterized by coarse particles with a high superficial area. Phosphorus content in sawdust was minimal. Total organic carbon in sawdust was 161 kg per compost pile. C/N ratio in sawdust was 200/1, while C/N ration in swine slurry was 7/1. On average, of three compost piles, 11.03 kg of N were applied and incorporated into the sawdust substrate. The initial compost biomass C/N ratio was 46/1. After 35 days, the C/N ratio of the biomass decreased to 26/1, pH maintained alkaline during the whole absorption phase.

2. RESULTS AND DISCUSSION: The temperature of the compost biomass ranged between 40 and 50ºC during the absorption phase. The moisture was maintained between 70 and 80%. When biomass moisture increased beyond 70%, the temperature of the compost pile decreased. Higher moisture content could allow the formation of anaerobic zones inside compost biomass, which is not desirable in this process. The $C\text{-}CO_2$ and $C\text{-}CH_4$ fluxes measured during the absorption phase are presented in the Figure 1. The letters A and R identify the days when slurry was applied and compost piles were rotated, respectively.

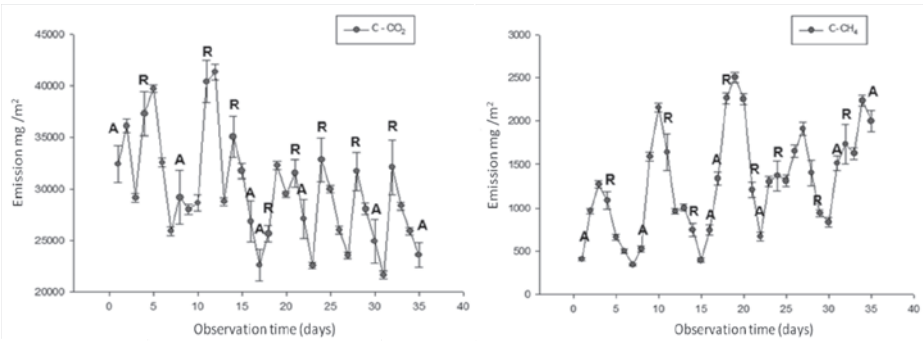

Figure 1. $C\text{-}CO_2$ and $C\text{-}CH_4$ fluxes during composting. Letter A identifies the days when slurry was applied to the substrate and R identifies the days when compost piles were rotated.

$C\text{-}CO_2$ and $C\text{-}CH_4$ emission profiles showed that increase of oxygen saturation when compost piles were rotated decreased emissions of these gases. However, slurry application increased $C\text{-}CO_2$ and $C\text{-}CH_4$ emissions. These results reinforce evidence for the presence of moments of higher reduction of oxygen concentration in compost piles, since the production of CH_4 occurs under anaerobic conditions, while CO_2 emissions are mainly aerobic.

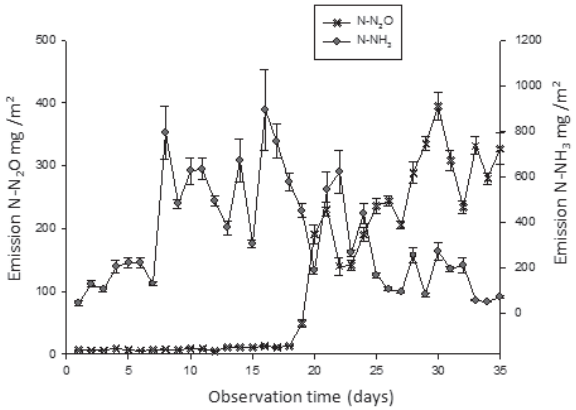

Figure 2. N-NH_3 and N-N_2O emission profile during swine composting.

The observation of N-N_2O and N-NH_3 emissions during the 35 days of the absorption period is shown in Figure 2. N-N_2O emissions became significant only when N-NH_3 emissions started to decrease after 18 days. By comparing the measured emissions for both gases and by results reported by Fukumoto et al. (2003), it is possible to conjecture that microorganisms had oxygen as the main energy source for the oxidation of organic carbon in the compost piles, limiting nitrate formation in the first 18 days. With the exhaustion of labile organic carbon, nitrate started to be produced. When compost piles were rotated, nitrate was displaced from the top to the bottom of the piles under anaerobic conditions, increasing N-N_2O emissions. Therefore, N_2O produced in the bottom layers of the compost piles was released when the substrate was rotated. The results of the mass balance for water, natural matter, dry matter, organic matter, carbon and nitrogen in compost piles are presented in Table 2. Mass balance indicates that 38.9% and 40.8% of the total nitrogen and organic carbon added to the system were lost during the composting process.

Table 2. Mass balance of water, natural matter (NM), dry matter (DM), organic matter (OM), organic carbon and total nitrogen in the compost piles.

	Water	NM	DM	OM	C	N
			kg			
Inputs (1)	2,485.16	2,935.97	450.80	406.90	233.77	11.63
Output (2)	1,124.49	1,448.26	323.77	288.32	142.82	6.88
Losses (1-2)	1,360.67	1,487.71	127.03	118.58	90.95	4.75
Measure emissions*	1,221.55	-	-	-	80.96	1.21
Gases/Losses (%)	89.77	-	-	-	89.01	25.47
Mass/Losses (%)	54.75	50.67	28.18	29.14	38.90	40.84

*Gases emissions: sum of C-CO_2 + C-CH_4, and N-NH_3+N-N_2O.

Total C and N losses measured by the mass balance of the compost piles were compared with the results of measured N-NH_3, N-N_2O, C-CO_2, and C-CH_4 emissions. The average N losses, as N-NH_3 and N-N_2O, accounted for 1.21 kg of nitrogen in relation to a total nitrogen loss of 4.75 kg, as determined in the mass balance. In the composting process, the main nitrogen losses occur as N_2 emissions (Paillat et al., 2005; Robin et al., 2006). Thus, considering that N-NH_3 and N-N_2O represented

25.47% of the total N losses, the remaining 74.53% could be considered as N_2 emissions.

Total C losses, as $C\text{-}CO_2$ + $C\text{-}CH_4$, totaled 80.96 kg during the 35 days absorption composting phase. $C\text{-}CO_2$ emissions accounted for 97% of the total C losses from composting piles.

CONCLUSIONS: In this study we found agreement between gas emissions assessment for $C\text{-}CH_4$, $C\text{-}CO_2$, $N\text{-}NH_3$, and $N\text{-}N_2O$, and the C and N mass balance in composting piles. When the compost piles were managed to ensure proper aeration, low emissions of N_2O and CH_4 were verified. Main gaseous losses of C and N occurred as N_2, NH_3 and CO_2, which are gases that present low global warming potential.

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AMMONIA EMISSIONS ASSOCIATED WITH SLATTED FLOOR AND BEDDED FLOOR SYSTEMS FOR FATTENING PIGS AND GESTATING SOWS

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ABSTRACT: Five batches of 32 fattening pigs and 3 batches of 10 gestating sows were successively housed. Each batch was divided into two homogeneous groups kept in two separate rooms fitted with either fully slatted floor (SFS) or bedded floor systems (BFS). Rooms were automatically ventilated. On average, the straw supply amounted to 400 and 920 g/pig per day for pigs and sows, respectively. The manure was removed after each batch. Fattening pigs were fed ad libitum and raised from 25 kg to about 110 kg. The space allowance was 0.75 and 1.2 m²/pig with SFS and BFS, respectively. Gestating sows were restrictedly-fed. Their average body weight was 210 kg. The space allowance was 2.5 m²/sow whatever the floor type. Emissions were measured by infra-red photoacoustic detection. From fattening rooms, emissions were 6.1 and 13.0 g NH_3/pig per day with SFS and BFS, respectively ($P<0.001$, s.e.=0.93). From gestating rooms, emissions were 12.8 and 9.1 g NH_3/sow per day, respectively ($P<0.01$, s.e.=1.23). Within a same floor type, emissions were significantly different between pig categories ($P<0.05$). Within SFS, higher emissions with gestating sows can be partly explained by the higher space allowance per pig (and thus a higher emitting surface). With BFS, higher emissions were observed with fattening pigs whereas the space allowance per pig was lower. In this case, results can be explained by the lower straw supply in proportion to excreted nitrogen (and thus a lower C/N ratio). One can conclude that NH_3 emissions from SFS are related to available space. With BFS, the amount of litter seems crucial to mitigate emissions.

Keywords: ammonia, fattening pigs, gestating sows, slatted floor, straw-based bedded floor

INTRODUCTION: In pig production, animals are usually kept on a slatted floor, mostly for economic and practical reasons. For several decades, there has been a renewed interest regarding litter systems, as they are associated with improved animal welfare, reduced odour nuisance and a better brand image for consumers. The aim of this study is to compare ammonia (NH_3) emissions associated with slatted floor (SFS) and bedded floor systems (BFS) for gestating sows and fattening pigs.

1. MATERIAL AND METHODS:

1.1. Experimental rooms, animals and feed: Two experimental rooms, similar in volume and surface, were arranged to successively house groups of 16 fattening pigs and groups of 5 gestating sows. One room was equipped with a slatted floor system (SFS) and another with a bedded floor system (BFS). In both rooms, ventilation was provided using an exhaust fan and the ventilation rate was automatically adapted to maintain a constant ambient temperature.

1.1.1. Fattening pigs: Five successive batches of 32 Piétrain × Belgian Landrace fattening pigs were divided into two homogeneous groups according to sex and body weight. The groups were kept separately in the two experimental rooms. In the pen with SFS, the space allowance was 12.2 m^2 (0.76 m^2 pig^{-1}). Before the arrival of the pigs, about 500 L of water was poured into the slurry pit to achieve a layer of about 4 cm. In the pen with BFS, the space allowance was 19.3 m^2 (1.21 m^2 pig^{-1}). The initial litter constituted an addition of 375 kg of whole wheat straw, representing a layer of 30-40 cm depth. Throughout the fattening period, fresh straw was regularly supplied up to a total amount of 750 kg (about 400g/pig per day). The pigs were fed ad libitum with commercial diets (17% crude protein content, CP). The fattening period lasted 4 months, from 25 to about 110 kg body weight. At the end of each fattening period, manure was removed and the pens cleaned.

1.1.2. Gestating sows: Three successive batches of 10 Belgian Landrace gestating sows were divided into two homogeneous groups according to the parity, body weight and backfat thickness. Groups were kept separately in the two experimental rooms. Pens were divided into a lying area and a feeding area. The rooms differed by the floor type of the lying area (SFS in one room and BFS in the other room). The surface of the lying area was 12.6 m^2 (2.5m^2 sow^{-1}) in both rooms. The feeding area consisted of five individual stalls (2.2 m x 0.6 m) placed on a concrete floor. The feeding stalls were equipped with front feeding troughs and rear gates, preventing access to the stalls outside of feeding time. Before the arrival of the sow, in the room with the slatted floor, 700 L of water was poured into the slurry pit to achieve a 5–6 cm water layer. In the room with the bedded floor, about 100 kg of whole wheat straw was used to constitute the initial deep litter of about 25 cm in depth. Thereafter, straw was weekly added to the litter, leading to a total amount of 285 kg of straw (about 920 g/sow per day). The sows were restrictedly fed with a commercial gestation diet (13% CP). The amount of daily feed was determined per sow as a function of parity and backfat thickness. The feed was supplied once a day at 8:00 a.m. and the sows were blocked in individual feeding stalls during feeding time (1 h). For each batch, the stay duration of the sows in the experimental rooms lasted about 9 weeks, from seven weeks after service until 7 days before farrowing. At the end of each gestation period, manure was removed and the pens were cleaned.

1.2. Gas emissions measurements: The NH_3 concentrations in the air of the experimental rooms and of the service corridor supplying fresh air were measured with a 1312 Photoacoustic Multi-Gas Monitor (Innova Air Tech Instruments). Sampling of the air in the rooms was performed above the exhaust fan, and sampling of the air of the corridor at about 1 m from the air inlets. The air was analyzed every hour. The ventilation rates were continuously measured by an electronic device (Exavent, Fancom®) and the hourly means were recorded. The emissions (E), expressed as mg h_{-1}, were calculated on an hourly basis using the following formula:

$$E = D \times (Cin - Cout) \qquad (1)$$

with D, the hourly mass flow (kg air h^{-1}); Cin and Cout, the gas concentrations in the room and corridor, respectively (mg kg^{-1} air). The hourly emissions were converted into daily emissions into g per animal. Series of measurements of six consecutive days were homogeneously spread throughout the animals' stay. There were four and three series of measurements per batch for fattening pigs and gestating sows, respectively.

1.3. Statistical analysis: Daily emissions were tested in the form of a mixed model for repeated measurements (proc MIXED) (SAS, 2005), including the effects of the floor (1 df), the physiological stage (1 df), the interaction between the floor and the physiological stage (1 df) and the series of measurement, expressed as a percentage of the stay duration (1 df), with 6 successive measurements per series. Residuals were normally distributed, with a null expectation (proc UNIVARIATE) (SAS, 2005). Correlation between successive measurements was modeled using a compound symmetry structure.

2. RESULTS AND DISCUSSION: Performances and climatic conditions observed during the experiments are presented in Table 1. Figure 1 shows the emission factors measured in the fattening and gestating rooms. For fattening pigs, emissions were 6.1 and 13.0 g NH_3 pig^{-1} day^{-1} with SFS and BFS, respectively ($P<0.001$, s.e.=0.93). From gestating rooms, emissions were 12.8 and 9.1 g NH_3 sow^{-1} day^{-1}, respectively ($P<0.01$, s.e.=1.23). Within a same floor type, emissions were significantly different between pig categories ($P<0.05$).

Table 1. Performances and climatic conditions in the experimental rooms (means ± sd between batches; SFS, slatted floor system; BFS, bedded floor system).

	Fattening pigs		Gestating sows	
	SFS	BFS	SFS	BFS
Initial body weight (kg)	23.8 ± 3.1	23.8 ± 3.0	194.7 ± 15.3	191.5 ± 11.8
Final body weight (kg)	111.7 ± 4.3	110.1 ± 4.9	228.4 ± 7.9	228.8 ± 7.9
Feed intake (kg day^{-1})	2.18 ± 0.11	2.24 ± 0.13	2.48 ± 0.02	2.49 ± 0.06
Nitrogen intake (g day^{-1})	59.2 ± 3.3	60.9 ± 2.6	51.6 ± 0.5	52.3 ± 0.9
Room temperature (°C)	20.5 ± 0.7	20.6 ± 1.2	20.3 ± 1.7	20.0 ± 1.8
Ventilation rate (m^3 h^{-1} pig^{-1})	81.4 ± 26.0	65.3 ± 23.3	298.3 ± 132.2	290.7 ± 127.4

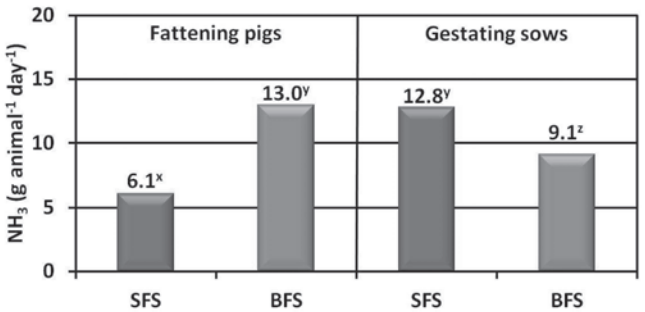

Figure 1. Ammonia emission factors (least squares means) measured from fattening and gestating rooms fitted with slatted floor system (SFS) or straw-based bedded floor system (BFS) (x, y, z: values with different subscripts differ significantly, $P<0.05$).

In the literature, comparisons between slatted floor and deep litter systems showed conflicting results regarding NH_3 emissions, as reviewed by Philippe et al. (2011). This can be explained by the wide range of rearing techniques, especially for pigs on litter. The bedded systems can differ as a function of the litter type (straw, sawdust, wood chip), litter management, space allowance and amount of supplied litter. These parameters influence the physical structure (density, humidity) and chemical

properties of the litter and thus gas emission levels. In the present study, the straw supplies amounted to 400 and 920 g pig^{-1} day^{-1} for fattening pigs and gestating sows, respectively, whereas the excreted nitrogen (Nex) was nearly similar for both pig categories regarding the difference of N-intakes and N-retention rates. According to Dourmad et al. (1999), the retained nitrogen represents 33 and 20% of the nitrogen intakes for fattening pigs and gestating sows, respectively. Thus, Nex was estimated to about 40 g pig^{-1} day^{-1} whatever the physiological stage. By increasing the amount of straw, the C/N ratio of the litter increases, which favours bacterial growth and promotes N assimilation into stable microbial protein with lower NH_3 emissions as consequence (Dewes, 1996). This explanation is supported by Gilhespy et al. (2009), who observed a reduction of NH_3 emissions with a greater straw supply (8 kg vs. 4 kg straw pig^{-1} $week^{-1}$).

Within SFS, NH_3 emissions were largely higher with gestating sows compared to fattening pigs, despite similar Nex. This result can be explained by the greater space allowance and thus the greater emitting surface, i.e. 2.5 m^2 per gestating sows and 0.76 m^2 per fattening pigs. This statement is in accordance with Guingand (2007), who measured a NH_3 emissions increase by 35% with space allowance increased by 43% for fattening pigs.

CONCLUSION: One can conclude that the amount of straw is crucial regarding NH_3 emissions associated with litter systems. With slatted floor systems, the available space seems more important than the level of excreted nitrogen.

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GASEOUS EMISSIONS FROM FATTENING PIGS OFFERED AN AD LIBITUM HIGH-FIBRE DIET AND KEPT ON FULLY SLATTED FLOOR: PRELIMINARY RESULTS

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ABSTRACT: The aim of this preliminary study was to measure the gaseous emissions from fattening pigs offered an ad libitum high-fibre diet (HFD) and kept on a fully slatted floor. A batch of 24 fattening pigs was divided into two homogeneous groups randomly allocated to a treatment: conventional cereals-based diet or high-fibre diet based on sugar beet pulp (23%). With HFD, a significant decrease in animal performance was observed (114.7 vs. 126.4 kg for the slaughter live weight; 837 vs. 962 g for the average daily gain). With pigs offered HFD, gaseous emissions per pig were significantly lower for ammonia (NH_3) (-30%, 6.64 vs. 9.47 g/d; $P<0.05$) and significantly greater for methane (CH_4) (+40%, 4.60 vs. 6.46 g/d; $P<0.05$). The emissions of nitrous oxide (N_2O) (0.34 g/d), equivalent carbon dioxide (CO_2eq) (0.27 kg/d), carbon dioxide (CO_2) (1.68 kg/d) and water vapour (H_2O) (2.11 kg/d) were not significantly influenced by the diet. In conclusion, HFD enabled a decrease in NH_3- and an increase in CH_4-emissions. However, in terms of climate change, this increase was offset by the decrease of indirect N_2O emissions due to NH_3-emission decrease, as indicated by the similar CO_2eq-emissions in the two groups.

Keywords: ammonia, fattening pigs, fully slatted floor, greenhouse gases, high-fibre diet, sugar beet pulp

INTRODUCTION: Agriculture significantly impacts the environment via emissions of polluting gases: ammonia (NH_3), which is responsible for eutrophication and for water and ground acidification and also contributes to indirect emissions of nitrous oxide (N_2O) and greenhouse gases (methane (CH_4) and N_2O), which are partly responsible for climate change. According to the literature, the diet composition can influence gas emissions. The aim of this preliminary study was to measure the gaseous emissions from fattening pigs offered an ad libitum high-fibre diet (HFD) and kept on a fully slatted floor.

1. MATERIAL AND METHODS: A batch of 24 fattening pigs was divided into two homogeneous groups randomly allocated to a treatment: conventional cereals-based diet or high-fibre diet based on sugar beet pulp (23%). The two diets (Table 1) were isoproteic (16%) and isoenergy (2226 kcal/kg net energy). The groups were kept simultaneously for a period of three months and separately in two identical rooms 103 m^3 in volume and equipped with a pen with a fully slatted floor (0.75 m^2/pig). In both rooms, ventilation was automatically adapted to maintain a constant ambient temperature. Gas emissions were measured by infrared photoacoustic detection (Innova) during 6 consecutive days at the 2^{nd}, 7^{th} and 12^{th} weeks of fattening.

Table 1. Composition of diets (as-feed basis).

	Conventional diet	High-fibre diet
Ingredient (%)		
Wheat	32.57	9.64
Wheat bran	10.94	9.18
Barley	15.00	15.00
Corn	15.00	15.00
Sugar beet pulp	-	23.00
Rapeseed meal	6.00	6.00
Soybean meal	9.43	12.40
Malt rootlets	3.00	3.00
Mineral-vitamin complex	5.79	4.34
Animal fat	1.03	1.82
Salt	0.31	0.31
Chalk	0.93	0.21
Monocalcium phosphate	-	0.10
Chemical composition (%)		
Crude protein	16.0	16.3
Crude fat	3.2	3.9
Crude ash	4.4	5.0
Crude fibre	4.3	7.5
Starch	42.4	31.7
Sugar	3.9	5.2
NSP[1]	18.00	30.00
Acid Detergent Fibre	6.08	10.00
Neutral Detergent Fibre	16.32	21.90
Net Energy (kcal/kg)	2225	2225

[1]Non-starch polysaccharides calculated as: dry matter - crude protein - crude fat - crude ash - starch – sugar

2. RESULTS AND DISCUSSION: With HFD, a significant decrease in animal performance was observed (114.7 vs. 126.4 kg for the slaughter live weight; 837 vs. 962 g for the average daily gain). With pigs offered HFD, gaseous emissions per pig (Table 2) were significantly lower for NH_3 (-30%, 6.64 vs. 9.47 g/d; $P<0.05$) and significantly greater for CH_4 (+40%, 4.60 vs. 6.46 g/d; $P<0.05$). The emissions of N_2O (0.34 g/d), CO_2eq (0.27 kg/d), CO_2 (1.68 kg/d) and H_2O (2.11 kg/d) were not significantly influenced by the diet. The lower NH_3-emissions could be attributed to the shift of a part of excreted nitrogen (N) from urine (as urea, a very volatile form of N) to faeces (as protein form, a more stable form of N) and to a lower slurry pH explained by the increase of volatile fatty acid content. These two phenomena result from a more significant microbial activity with fibrous diets. The higher CH_4 emissions could be explained by greater production in the digestive tract and in the slurry due to fibre fermentation.

Table 2. Gas concentrations and emissions per day and per sow.

	Conventional diet	High-fibre diet	Significance
Concentrations			
NH_3 (ppm)	7.87 ± 2.40	6.42 ± 2.27	NS
N_2O (ppm)	0.39 ± 0.02	0.39 ± 0.03	NS
CH_4 (ppm)	6.78 ± 0.55	7.75 ± 0.67	*
CO_2 (ppm)	761 ± 45	773 ± 55	NS
H_2O (g/m³)	11.6 ± 0.9	11.9 ± 0.8	NS
Emissions			
NH_3 (g)	9.47 ± 4.62	6.64 ± 4.10	*
N_2O (g)	0.33 ± 0.07	0.34 ± 0.06	NS
CH_4 (g)	4.60 ± 1.36	6.46 ± 1.59	*
CO_2eq (kg)	0.25 ± 0.07	0.29 ± 0.07	NS
CO_2 (kg)	1.65 ± 0.28	1.70 ± 0.26	NS
H_2O (kg)	1.79 ± 0.44	2.43 ± 0.31	NS

NS: $P>0.05$; * : $P<0.05$

CONCLUSION: In conclusion, HFD enabled a decrease in NH_3 and an increase in CH_4 emissions. However, in terms of climate change, this increase was offset by the decrease of indirect N_2O emissions due to NH_3 emission decrease, as indicated by the similar CO_2eq emissions in the two groups.

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ESTIMATION OF LEVELS OF NITROGEN VOLATILIZATION IN POULTRY BARNS FROM FIELD MEASUREMENTS

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ABSTRACT: The level of nitrogen volatilization in CORPEN's references is about 30% of nitrogen excreted. However, improved breeding practices, changes in genetic strains and in feeding contribute in modifying this level of nitrogen volatilization. Institute of French Poultry (ITAVI) and the National Institute of Agronomic Research (INRA) collaborated to create a simplified method of emissions measurement in poultry barns (concentrations ratio method associated with a mass balance on C, N, P and H_2O). The initial results from measurements made on 24 batches of broilers (lightweight, standard and heavyweight production) enable representative measurements and refine the references currently used by authorities.
For overall losses of nitrogen in poultry barns, the average value measured is 19% (from mass balance default on nitrogen). Depending on the season, the average is between 15.7% in the intermediate season and 23.6% in the cold period. Depending on the type of production, the results vary from 17.5% in lightweight broiler production (~ 36 days of age) to 21% in standard broiler production (~ 42 days of age).
For nitrogen volatilization from excretion, measurements show 37.5% volatilization in buildings. A small variation is observed depending on the cool or warm period, whereas amounts greatly increase during the intermediate season (44%). The nitrogen volatilization from excretion for short broiler productions seems higher (volatilization for lightweight broiler production>standard production>heavyweight production).
The results of these field measurements can refine the references used today, and once validated by authorities, can be used to obtain emission factors representative of production practices and climatic conditions.

Keywords: gaseous emissions, broiler, nitrogen volatilization, ammonia

INTRODUCTION: Nitrogen management is becoming a significant concern for public authorities (environmental impacts related to eutrophication, acidification and greenhouses gas) and for agricultural sectors (management of landspreading). Moreover, nitrogen emissions represent an important issue because of increased regulations related to international objectives in which France is engaged (including the Gothenburg protocol).

Today, few references on nitrogen emissions from poultry rearing and from field measurements are available in the bibliography. For poultry manure, CORPEN's documents present levels of overall losses in buildings ranging from 18% (broilers) and 37% (turkeys) in field conditions and around 30% under experimental conditions. These elements were calculated from a nitrogen mass balance (intake - fixed - excreted).

To complement these references, we present the initial results from measures in 24 commercial buildings for three kinds of broilers: Lightweight (35 days of rearing: LW), Standard (42 days of rearing: ST), and Heavyweight broiler production (56 days

of rearing: HW) in Brittany. This will enable updating and enhancing, after confirmation by authorities, of references used by the profession. The realization of this measurement campaign is justified by the continuous improvement of farming practices, the evolution of strains (genetic) and dietary changes since 2008, and the need to establish emission factors that are representative of field practices and climate conditions.

1. MATERIAL AND METHODS START WITH HEADING:

1.1. Using the simplified method of measurement of GHG emissions in poultry barns: The method used to implement the measures is the simplified method in rearing buildings developed by the National Institute of Agronomic Research (INRA) and the Institute of French Poultry (ITAVI) (Ponchant and al, 2009). The main advantage of this simplified method is the ability to multiply, for a low cost, the field measurements to include the variability of breeding practices in the development of future emission factors. For each emission measurement in rearing, we made three samples per batch (beginning, middle and end of the batch), during which we made air samples from inside and outside with Tedlar® bags. The achievement of mass balances was permitted in answer to a Zootechnical questionnaire, the use of flock sheets and the order of food delivery.

1.2 Measurement of air samplings and calculation of gaseous emission: Gaseous emissions were estimated from the method of concentration ratios defined in the simplified method of measurement (Ponchant and al, 2009). The gaseous concentrations of air samples taken inside and outside the broiler house were quantified by photoacoustic infrared spectrometry (INNOVA 1412®).

Therefore, emission calculations are made from the default mass balance on carbon (carbon loss) (eq 1) and (eq 2). By including the median values of gas concentrations inside and outside the building, we obtain averages of concentration gradients.

C litter + C chicks + C food - C broilers - Cmanure = loss of C (éq. 1)

Loss of C = C-CO_2 Emission + C-CH_4 Emission (éq. 2)

Thus, the different emissions can be calculated according to the following equations;

C-CO_2 emission = Loss of C/ [1 + (concentration gradient C-CH_4 / concentration gradient C-CO_2)]

Gas Emission = C-CO_2 emission x (gas concentration gradient / concentration gradient C-CO_2)

1.3 Characterization of solid manure and estimation of nitrogen losses: Weightings and physico-chemical analysis were performed on the solid manure issued in most broiler buildings at the end of batches and after removal of animals. Solid manure samplings were conducted in several sites of the building (between 15 and 20 samples pooled and thoroughly mixed). All solid manure from each broiler house was weighed at the end of the batch. When this could not be done, we used bibliographic references to determinate the quantity and composition of broilers' manure. Nitrogen losses through volatilization in broiler houses (mainly NH_3, but also N_2O and N_2) were estimated using the mass default balance for nitrogen. These rates of nitrogen losses correspond to the proportion of nitrogen excreted by animals, which is not

found in solid manure at the end of the batch, and which is therefore lost by volatilization.

2. RESULTS:

2.1. Nitrogen losses overall: Overall losses of nitrogen calculated from the default of the mass balance for nitrogen are an average of 19%. These values are consistent with those of CORPEN. However, the measurements enable highlighting variability in global losses of nitrogen according to the rearing period (warm, cold or intermediate season ; table 1). The calculated mean values range from 15.7% for the intermediate season to 23.6% in cold periods (17% for the hot season). When we express the results by type of production, the variability is less significant. Additionally, the mean values ranged from 17.5% for LW broiler production to 21% for ST broiler production (18.8% for HW broiler production).

Table 1. Results of Nitrogen Losses overall from mass balance.

	Nitrogen Losses			
	Average	Standard deviation	Mini	Maxi
	%	%	%	%
LW broiler production	17,5	5	10	27
ST broiler production	21	9,3	11	36
HW broiler production	18,6	3,4	16	24
Cold period measurements	23,6	8	13	36
Warm period measurements	17	5,4	10	27
Intermediate period measurements	15,7	1,2	14	17

2.2 Volatilization of nitrogen excreted: The measurements indicate an average value of 37.5% volatilization from excreted nitrogen. In the cool or warm periods, average values are close to the overall average of our sample (37.4% for the cold period and 35.3% for the warm period). Volatilization of nitrogen increases during the intermediate period (44%). The variability of results is greatest for the warm period (minimum and maximum gap of 31.6%). This trend is related to different farming practices in hot weather (mist, strong mixing of the air and high level of building ventilation).

The results expressed by types of production show values higher than those of CORPEN's references for ST broiler production (38.4%) and LW broiler production (40.6%). For HW broiler production, we obtain an average value of 29.5% nitrogen volatilization from excretion. It seems that the shorter and more intense the production cycle, the greater the share of nitrogen volatilized from excretion is significant.

2.3 Ammonia emission: Measurements also show a proportion of nitrogen volatilized as ammonia as 7.6% of excreted nitrogen (or 81.4% of the volatilized nitrogen). Volatilization as ammonia appears lower in the cold (6.4%) and warm periods (7.7%) than in the intermediate season (9.5%).

Depending on the types of production, values of nitrogen volatilized as ammonia range from 6.5% for LW broiler production, 7.9% for ST broiler production and 9% for HW broiler production, compared to excretion. These results show that the longest

durations of rearing are those that emit the most ammonia. This is explained by the litter quality, which is difficult to maintain with advancement of the batch.

CONCLUSION: The results of these field measurements show some variability in nitrogen loss and volatilization of nitrogen as ammonia according to the climatic periods and production methods in broilers buildings. These measures must be completed for other poultry species (turkeys, ducks) and other areas of production. Finally, these results provide a basis for refining the references used today. Once validated by authorities, they may be used to obtain representative emission factors for national production practices and defined climatic conditions.

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AMMONIA AND PARTICULATE MATTER EMISSIONS FROM AN ALTERNATIVE HOUSING SYSTEM FOR LAYING HENS

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ABSTRACT: To obtain more data on the environmental impact of alternative egg production facilities, a monitoring campaign was developed to measure the ammonia and particulate matter (PM_{10}) emissions from a commercial house for laying hens, which was equipped with an aviary system. The data were collected continuously in three periods of approximately 1 week each, distributed over a six-month period, using an infrared photoacoustic detector (Bruel&Kjaer) to measure NH_3, and a laser detector to measure particulate matter. The NH_3 emission factors were compared to conventional cage systems and showed that ammonia emissions from the aviary were higher than those of a battery cage system with ventilated belts, but lower than the deep-pit system with hens in cages, (i.e. the ammonia emissions of alternative cages were not much higher than some cage systems). On the contrary, dust emissions in the aviary were 5.7 times higher in comparison with the caged system.

Keywords: laying hens, non-caged system, dust emissions, ammonia emissions

INTRODUCTION: The EU farms of laying hens are on the threshold of a profound transformation that will involve major changes in housing facilities. This transformation arises from the European directive (1999/74 EC) that sets minimum welfare standards for laying hens and bans conventional cages from 2012 onward. It is commonly accepted that the alternative systems, just because they allow greater movement of chickens, involve a higher level of ammonia emissions, which is the pollutant with greater relevance for the poultry sector, and particulate matter. The objective of this study was to evaluate these aspects in a poultry farm of laying hens located in Northern Italy.

1. MATERIAL AND METHODS: The study was performed at a commercial laying hen farm, located in the Province of Bologna, Italy, breeding 20,000 layers with an aviary system. The building is subdivided into 7 sections 20m long to better manage the hen groups. The birds can move inside the house on three levels with feeding, watering, and perches provided on each tier, and also have access to outside in a free-range area. The aviary incorporates cleaning belts under the floor of each tier to ensure that manure is conveyed from the different tiers and deposited outside the house under a shelter. Removal of the droppings is performed twice a week. On the two lower tiers of the aviary there are two lines of automatic nests with an egg collecting system. The nests are automatically closed from 21:30 to 6:30 to avoid the layers using them as bedding in time of non-deposition. The concrete floor is fully littered. Ventilation is provided by 10 extraction fans of 1.3 m diameter, mounted on the front of the building with air inlets on the opposite wall and side. The maximum ventilation rate is 30,000 m^3 h^{-3} for each fan. The ventilation strategy is computer controlled and based on thermostatic regulation.

1.1. Ventilation rate and environmental parameters: Ventilation rate, temperature and humidity were continuously recorded during the 6 months of the experiment. The

ventilation rate was monitored by recording the number of active fans and the rotation rate by frequency inductive sensors (mod. XS4P30PA340, Telemecanique). The correlation between rotation frequency and air flow rate was calculated by using on-site anemometric measurements (Testo 490 vane anemometer), taken for each monitoring cycle and for each ventilation step. The temperature and relative humidity were monitored constantly both inside and outside the houses with dataloggers (HOBO H8 Pro, ONSET Computer Corporation).

1.2. Ammonia and particulate matter emissions: The monitoring program lasted 6 months, with three weekly measuring campaigns distributed over different seasons (summer, autumn, winter). The ammonia and particulate matter emissions were calculated as the multiplication of pollutant concentration (outlet – inlet difference) with the ventilation rate, recorded at the same time, collecting data every 5 minutes. Ammonia concentration was continuously measured at the exhaust fans using an infrared photoacoustic detector IPD (Bruel & Kjaer, Multi-gas Monitor Type 1302). PM_{10} concentration was continuously monitored by an instrument (Microdust-Pro-Aerosol Monitoring System, Casella, UK) whose measurement principle is based on infrared light scattering (wavelength of 880nm). It allows immediate and continuous measurement of the concentration in mg m^{-3} of airborne dust particles within a wide range of aerodinamic diameter (0.1-10 μm). The online measurements were checked and corrected by a number of concurrent gravimetric measures.

1.3. Manure characteristics and ammonia emissions: The manure characteristics were analyzed in different positions along the belt under the perches and at the discharge outside of the house to study the influence of the drying level of the droppings on emissions.

2. RESULTS AND DISCUSSION:

2.1. Environmental parameters: The ventilation rate of the hen house shows an average value of 5.3 m^3 h^{-1} hen^{-1}, with a wide variation between the extremes of values recorded in winter (1.3 m^3 h^{-1} hen^{-1}) and in summer (12.4 m^3 h^{-1} hen^{-1}), confirming that in Italy the range can be more than 10 times larger. Effective environmental control made it possible to significantly reduce extremes in temperature with internal temperatures ranging from 19.0 to 34.7 °C, as compared to external temperatures between 3.7 and 37.3 °C (Table 1).

Table 1. Environmental parameters recorded during the study.

Parameters		summer	autumn	winter	*mean*	*St.Dev*	*Min-Max*
Air flow rate	[m^3 h^{-1} hen^{-1}]	11.3	3.1	1.6	*5.3*	*0.6*	*1.3-12.4*
Indoor temperature	[°C]	30.6	23.0	19.9	*24.5*	*1.1*	*19.0-34.7*
Outdoor temperature	[°C]	29.7	13.7	5.1	*16.2*	*2.5*	*3.7-37.3*
Indoor RH	[%]	52	67	68	*62*	*3*	*41-76*
Outdoor RH	[%]	54	97	96	*82*	*6*	*35-100*

2.2. Ammonia and Particulate Matter emissions: The pattern of ammonia emissions and particulate matter from the layer house, between two successive removals of the droppings from the manure belts, for the summer and winter monitoring periods, is shown in Figure 1 for NH_3 and in Figure 2 for PM_{10}.

In both periods one notices a progressive increase in the ammonia emission level as the manure accumulates on the belt, but in the summer period one also notices the day and night variation, due to variation in the ventilation regime, while in the winter period the daily pattern is much less apparent.

In the case of PM_{10} emissions, the daily trend is clearly visible, with low values during the night and a sharp increase during the day, when animal activity starts and the ventilation rises. Particularly accentuated peaks occurred in the cleaning moments of the manure belts. In correspondence with this operation, however quite short (about 20'), an increase was recorded of the PM_{10} concentration values by 2-3 times.

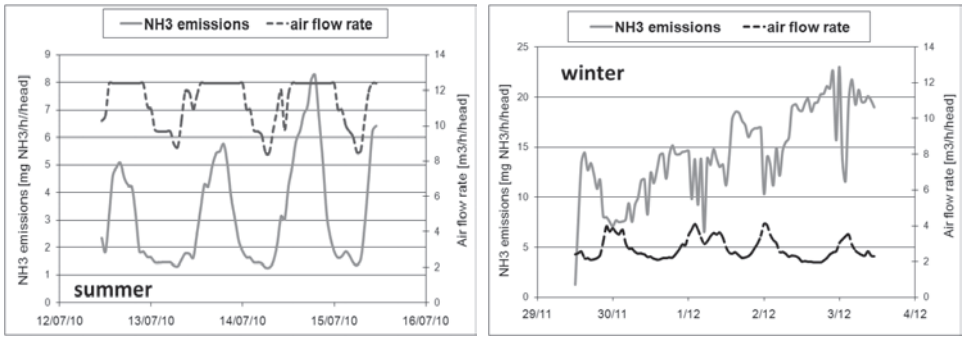

Figure 1. Daily pattern of the ammonia emissions for the summer and winter periods.

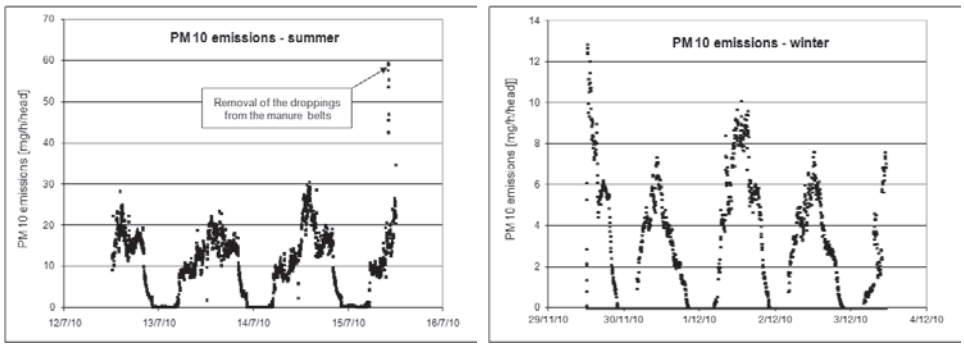

Figure 2. Daily pattern of the PM_{10} emissions for the summer and winter periods.

The annual emission factors of ammonia and PM_{10} from the layer house, averaged on the three seasonal monitoring campaigns, are summarised in Table 2.

The average ammonia emission factor was 0.116 kg NH_3 $head^{-1}$ y^{-1}, an intermediate value compared with previous studies performed by our institute (Fabbri et al., 2007) for laying hens housed in conventional cages, which gave values of 0,063 kg NH_3 $head^{-1}$ y^{-1} for the ventilated belt technique, of 0.152 kg NH_3 $head^{-1}$ y^{-1} for the non-ventilated belt technique, and 0.162 kg NH_3 $head^{-1}$ y^{-1} for the deep-pit technique.

Table 2. Average ammonia and PM_{10} emissions of the laying hen house.

Parameters		summer	autumn	winter	mean	*St.Dev*	*Min-Max*
NH_3	[kg head^{-1} y^{-1}]	0.030	0.182	0.137	0.116	*0.018*	*0.0-0.260*
	[kg LU^{-1} y^{-1}]	0.026	0.161	0.121	0.103	*0.016*	*0.0-0.230*
PM_{10}	[g head^{-1} y^{-1}]	87.7	37.1	13.9	46.2	*46.6*	*0-549.9*
	[g LU^{-1} d^{-1}]	77.5	32.8	12.3	40.8	*41.2*	*0-486.0*

The relatively low emission factor measured in this study arises, in particular, from the low results during the summer period, with the NH_3 concentration close to the limit of the instrument's detection. This confirms that the high dry matter content of hen droppings, that in summer exceeds 60%, has the effect of a significant reduction of NH_3 emissions. Even the litter on the ground has always shown a high dry matter content, exceeding 90% in summer and 70% in other seasons. The emission values measured in the colder seasons, however, were lower than expected, considering that for the alternative system, the literature findings indicate ammonia emissions are quite higher than those of the caged systems.

The PM_{10} emission factor was 46.2 g head^{-1} y^{-1}, with a large range in the extreme values. Compared to a previous study made in a battery cage house with ventilated belts, which showed an average emission factor of 8 g head^{-1} y^{-1}, this result was 5.7 times larger, confirming the higher particulate matter emissions of the alternative systems.

CONCLUSION: In our study the ammonia emissions of an aviary equipped with manure belts were not much higher than some of the systems in conventional cages. This is in contrast with the findings of the international literature (Roumeliotis 2008, Defra, 2009) that, in general, reports emissions of ammonia and particulate matter significantly higher in the case of laying hens in battery cages than in alternative systems. Conversely, our results on PM_{10} emissions are in line with the findings that the alternative systems produce significantly higher fine particulate emissions than caged layer houses.

A possible explanation of the differences between our results and those reported in other studies is the climatic conditions of our country, which lead to a high air flow ventilation rate and drying of the manure that reduces emissions of ammonia, but also increases the emission of particulate matter.

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Part II.
Emitting processes

N_2O EMISSIONS FROM SOIL AMENDED WITH CATTLE SLURRY UNDER MEDITERRANEAN CONDITIONS

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ABSTRACT: N_2O emissions are affected by several factors, including type of fertilizer, edapho-climatic conditions and applied mitigation measures. A field experiment was performed in central Portugal for two consecutive years to evaluate the effect of soil N_2O emissions originating from the application of cattle slurry (CS) to a double-cropping system producing maize and oats. The use of a nitrification inhibitor (DCD) was evaluated as an emission mitigation measure. A mineral fertilizer treatment (MIN) and a Control were included and the DCD effects were tested together with MIN (MIN+DCD) and CS (CS+DCD). Total N input was equal for all fertilizing treatments (oat 80 kg N ha^{-1}; maize 170 kg N ha^{-1}). N_2O fluxes were measured on 165 sampling dates, using a photo-acoustic spectroscopic infrared gas analyzer. The most important fluxes were observed 8-10 days after fertilizer incorporation and during the following 20-40 days. Annual N_2O-N losses were higher in the first year, with a wetter autumn and a warmer summer than usual. The highest values were measured with the use of mineral fertilizers (4.65 and 4.21 kg N ha^{-1} in MIN+DCD and MIN, respectively), which were 60-70% higher than those measured with slurry application or without fertilization (1.85, 1.55 and 1.33 kg N ha^{-1} in CS+DCD, CS and Control, respectively). Mean annual values of the emission factor based on N application (EF) were 0.76, 0.63, 0.12 and 0.07%, in MIN+DCD, MIN, CS and CS+DCD, respectively. The DCD use, especially with mineral fertilizer, did not produce any evident effect on total N_2O losses.

Keywords: GHG emissions, soil fertilization, nitrogen, nitrification inhibitor

INTRODUCTION: Nitrous oxide (N_2O) is involved in global warming and destruction of stratospheric ozone (Bouwman, 1990). According to greenhouse gas inventory reports published this year, during 2010 N_2O emissions were responsible for 7.2 % of total EU-27 GHG emissions (excluding LULUCF). In Portugal, they represented 6.7% of total GHG emissions, 90.4% associated with direct and indirect emissions from agricultural soils. Microbial nitrification and denitrification are the two mechanisms responsible for N_2O emissions from soil, being seasonal dynamics in those emissions largely regulated by N-input in the soil and soil moisture status (Verma et al., 2006).

The default IPCC emission factor, i.e. the percentage of applied N emitted as N_2O, is 1% (IPCC, 2006). However, N_2O emissions are affected by several factors, including edapho-climatic conditions (Dobbie and Smith, 2003), type of fertilizer incorporated into the soil (Jones et al. 2007) and use of nitrification inhibitors (Di and Cameron, 2012).

The use of the nitrification inhibitor dicyandiamide (DCD), together with nitrogen fertilizers applied to crops, is usually associated with a reduction of N_2O emissions

from soils. However, there are also reports of no or contradictory effects from the use of DCD on N losses, particularly through N_2O emissions (Merino et al., 2001).

A field experiment was performed in central Portugal from May 2006 to May 2008 to evaluate the effect of soil N_2O emissions originating from cattle slurry applied to a double-cropping system producing oats and maize. The use of DCD, added to the organic effluent or incorporated into a mineral fertilizer, was also studied as a mitigation measure.

1. MATERIAL AND METHODS: A field experiment using a double-cropping system producing oats and maize was conducted over a 2-year period (May 2006 to May 2008) on a farm in central Portugal (Castelo Branco). The Castelo Branco region has a Mediterranean influence (821 mm average annual rainfall, 15.6°C mean annual temperature) with 90% of annual rainfall concentrated in an 8-month period (October–May). Temperature and rainfall data were recorded daily at an on-site weather station during experiments and important differences were observed over the years. On July 2006, very high temperatures were recorded (maximum daily-values above 36°C between days 8 and 18). Autumn 2006 was the third most rainy since 1931, while 2007/2008 (year 2 of the experiment) was one of the driest years of the last decade.

The soil was a Cambisol, with 0.81% organic C, pH (H_2O) 6.2, and high P_2O_5 and K_2O levels (>120 mg kg^{-1}). The treatments (Table 1) consisted of the application of cattle slurry (CS) and implementation of traditional mineral fertilization (MIN). A Control treatment (with no fertilization) was included, and the DCD effects were tested together with MIN (MIN+DCD) and CS (CS+DCD). Nitrogen forms applied using conventional mineral fertilizers were: ammonium sulphate at sowing and ammonium nitrate in the top-dressing applications (February/March for oats and early July for maize). For treatment MIN+DCD, a commercial fertilizer with DCD (Nitrotop®) was used, which contained 20% of N (urea and ammonium sulphate) and about 1.4% of DCD. DCD (12 kg active ingredient ha^{-1}) was diluted and mixed thoroughly with the slurry just before the spring and autumn applications. Slurry was incorporated into the soil just before crop sowing. Total N input was equal for all fertilizing treatments (oats 80 kg N ha^{-1}; maize 170 kg N ha^{-1}), but application time differed (Table 1).

The field was divided into $45m^2$ (5.6m x 8m) plots and the experimental design was randomized blocs with 3 replications. N_2O fluxes were measure on 165 sampling dates. The measuring frequency was diary in the first 15 days after fertilizer application, and 3-5 days during the remaining growing season. Measurements always occurred between 11 AM and 1 PM. N_2O concentrations were measured using a photo-acoustic spectroscopic infrared gas analyser (1412 Photoacoustic Field Gas-Monitor, Innova Air-Tech Instruments) in the headspace of PP chambers with a 24cm diameter and a 16.5cm height inserted into the soil to a 5cm depth of; the chambers were kept in fixed places throughout the season. Two chambers per plot (6 per treatment) were used. Gas samples were taken when chambers were closed (t0) and 1h later (t1), and fluxes were calculated based on changes in headspace concentrations at t1 and t0. The concentrations were corrected by the analyser to a 20°C temperature and included relative humidity in the sample taken. The calculated hourly emissions were integrated over time to estimate the total daily emission and the emission over the measurement period during each season. The emission factor based on N application (EF) was calculated using $EF(\%) = 100 \times ((N_2O_{fert} - N_2O_{Control}) / Nap)$, where N_2O_{fert} represents the cumulative N_2O flux (kg N ha^{-1}) in the fertilized plot,

$N_2O_{Control}$ the cumulative flux in the zero-N treatment, and Nap the amount of applied N (kg N ha^{-1}).

Table 1. Amounts (kg ha-1) of N applied in each culture and treatment, through organic and mineral fertilizers.

Treatment	Oats			Maize		
	Organic fert.	Mineral fert.		Organic fert.	Mineral fert.	
		Initial	Cover		Initial	Cover
Control	0	0	0	0	0	0
MIN	0	30	50	0	90	80
MIN+DCD	0	80	0	0	170	0
CS	80	0	0	170	0	0
CS+DCD	80	0	0	170	0	0

2. RESULTS AND DISCUSSION: In both cultural periods (spring-summer and autumn-winter) N_2O fluxes (data not shown) were greater between 8-10 and 30-40 days after crop sowing. The higher value (practically 300 g N-N_2O ha^{-1} day^{-1}) occurred during the rainy autumn with mineral N fertilization, which confirms the importance of the simultaneity of precipitation and greater mineral N availability for higher N_2O emissions.

As observed in other field trials performed under different conditions (e.g. Jones et al., 2007), differences in temperature and precipitation (soil water content) generated inequalities between the N_2O-N losses measured in each year (Table 2). In the first year, the highest values were measured in MIN+DCD and MIN (4.65 and 4.21 kg N ha^{-1}, respectively), which were 60-70% higher than those measured in CS+DCD, CS or in the Control (1.85, 1.55 and 1.33 kg N ha^{-1}, respectively). During the second experimental year, the N_2O-N losses in the different treatments were much similar, ranging from 0.45 kg N ha^{-1} $year^{-1}$ in the Control to 0.92 kg N ha^{-1} $year^{-1}$ in MIN+DCD.

*Table 2. Total cumulative N_2O-N losses and emission factor based on N application (EF) observed during the experiment. Values in parenthesis represent s*tandard error of the mean; n=6.

Treatment	Year 1		Year 2	
	Total N_2O-N losse (kg N ha^{-1})	EF (%)	Total N_2O-N losse (kg N ha^{-1})	EF (%)
Control	1.33 (0.09)		0.45 (0.03)	
MIN	4.21 (0.40)	1.15 (0.15)	0.70 (0.13)	0.10 (0.05)
MIN+DCD	4.65 (0.32)	1.33 (0.12)	0.92 (0.12)	0.19 (0.06)
CS	1.85 (0.21)	0.21 (0.08)	0.50 (0.08)	0.02 (0.02)
CS+DCD	1.55 (0.09)	0.09 (0.05)	0.58 (0.04)	0.05 (0.02)

With the use of CS, the N_2O-N annual losses did not exceed 2 kg N ha^{-1}, less than half of the maximum value reached with mineral fertilizers. This result could be explained by the addition of organic carbon, which would have stimulated O_2 demand, N_2O consumption and a decrease in the N_2O/N_2 ratio (Vallejo et al., 2006). During the first autumn-winter period, the use of DCD in both fertilizers promoted significant

reductions in daily N_2O-N emissions (data not shown), but not in the cumulative N_2O-N emitted during this period. Gioacchini et al. (2002) suggested that DCD can have a priming effect in the net mineralisation of organic N in soil, resulting in greater long-term nutrient loss.

Considering the results presented in Table 2, it is evident that the N_2O emission factor of 1% seems acceptable to estimate N_2O-N losses from soils where mineral fertilizers were applied, but clearly overestimate the losses from soils amended with cattle slurry. With application of mineral fertilizers, the two years' mean emission factors were 0.76 and 0.63% in MIN+DCD and MIN, respectively. Is important to note that in a year with a rainy autumn an EF superior to 1% could be expected, while in drier years the EF will have a significantly lower value. With slurry application, the EF annual value did not exceeded 0.12%.

CONCLUSION: Concurrent conditions of high soil mineral-N content and high soil water content (precipitation) promoted significant N_2O-N emissions, explaining the higher N_2O-N losses when mineral fertilizers were applied during a rainy autumn. The 1% N_2O IPCC emission factor seems acceptable to estimate N_2O-N losses when mineral fertilizers are applied to soils. However, it clearly leads to the overestimation of the losses in the case of soils amended with cattle slurry. In the experimental conditions under scrutiny, the use of DCD as a nitrification inhibitor added to mineral fertilizer or slurry did not influence annual N_2O-N losses.

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METHANE EMISSION AND MILK PRODUCTION OF DAIRY-COW GRAZING PASTURES RICH IN LEGUMES OR GRASSES IN URUGUAY

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ABSTRACT: Understanding the impact of changing pasture composition on reducing GHG emissions in dairy grazing systems is an important issue to mitigate climate change. The aim of this study was to daily estimate CH_4 emissions of dairy cows grazing on two mixed pastures with contrasting composition of grasses and legumes: L pasture (60% legumes on DM basis) and G pasture (76% grasses on DM basis). Milk production and CH_4 emissions were compared over two periods of 2 weeks during spring using 8 lactating Holstein cows in a 2×2 Latin square design. Herbage organic matter intake (HOMI) was estimated by chromic oxide dilution and herbage digestibility (OMD) was estimated by faecal index. Methane emission was estimated by using the SF6 tracer technique adapted to collect breath samples over 5-day periods. OMD (0.71) and HOMI (15.7 kg OM) were not affected by pasture composition. Milk production (20.3 kg/d), milk fat yield (742 g/d) and milk protein yield (667 g/d) were similar for both pastures. This may be explained by the high herbage allowance (30 kg DM above 5 cm/cow) which allowed the cows to graze selectively, in particular in grass sward. Similarly, methane emission expressed as absolute value (516 L/cow/d) or expressed as methane yield (6.6% GEI) was not affected by treatments. In conclusion, at a high herbage allowance, the quality of the diet selected by grazing cows did not differ between pastures rich in legumes or rich in grasses, and therefore there was no effect on milk or methane production.

Keywords: dairy cows, grazing, CH_4, measuring method, SF_6

INTRODUCTION: The growing global concerns of climate change, among other environmental issues, have moved researchers and farmers to include environmental impacts together with productivity when evaluating and optimizing farming systems. Uruguayan ruminant production systems are predominantly pasture-based with approximately 75% of agricultural land within Uruguay dedicated to pasture. As a result of its relatively high ruminant population, enteric methane (CH_4) emissions contribute to approximately 50% of Uruguay`s total greenhouse gas emissions as CO_2 equivalents, according to the National Greenhouse Gases (GHG) Inventory (DINAMA, 2010). Therefore, estimating GHGs emissions is especially important for Uruguay. Mixed legume-grass pastures are the basis of dairy production in Uruguay and therefore increasing the proportion of legumes in the diet of grazing animals could be a practical way to reduce national methane emissions, as well as improving livestock performance. For this study, we used the sulphur hexafluoride (SF_6) tracer technique reported by Johnson et al. [8] adapted to collect breath samples across periods of 5 days (multi-day sampling), instead of the original 24 h sampling (Gere and Gratton, 2010). Multi-day sampling favors animal welfare, simplifies logistics in the field, and reduces the number of samples necessary for analysis. This work is one of the first applications of the extended sample period adaptation of the tracer technique to freely grazing cows. The main objective of this study was to estimate,

through the SF6 tracer technique adapted to multi-day sampling, daily methane emissions of lactating dairy cow grazing pastures with contrasting legume content.

1. MATERIAL AND METHODS: The experiment was performed at the Experimental Station of the Faculty of Agronomy (34º 36´S, 56º 13´ W) during the spring (17/10 to 27/11/2010). Treatments consisted of two pastures with contrasting composition: one rich in legumes (Medicago sativa L. and Trifolium repens L.), referred to as legume sward hereafter, and the other pasture rich in grasses (Lolium multiflorum Lam.), referred as grass sward hereafter. A replicated 2x2 Latin square design was used with eight lactating Holstein cows over 2 periods of 21 days (with 7 days of dietary adaptation and 14 days of faeces collection and methane measurements). The animals were allotted according to pre-experimental milk production (24.9 ± 4.15 kg/d milk), live weight (536 ± 18 kg) and lactation stage (195 ± 7 days). Swards were strip-grazed at a daily minimum amount of 30 kg DM/cow/day (above 5 cm).

1.1. Herbage measurements: Herbage mass and mean sward heights were measured before and after grazing four times during each period. On the same days as the determination of pre-grazing herbage mass, three handfuls of herbage were cut at ground level to determine the proportion of legume and grass of the herbage offered and chemical composition of the defoliated herbage (by cutting at a height corresponding to the mean post-grazing sward height).

1.2. Measurements on dairy cows: Individual herbage OM intake was determined using chromic oxide to estimate faecal OM output, and N and ADF contents in the faeces (g/kg OM) to estimate herbage OM digestibility of herbage (Comeron and Peyraud, 1996). The cows were milked twice, and individual milk production was recorded. Cows were weighed on the last day of each experimental period. The CH_4 emission was measured using the SF_6 tracer technique reported by Johnson et al. (1994). The SF_6 permeation tube (PT, provided by the NIWA, National Institute of Water and Atmospheric Research, New Zealand) was introduced per os into the rumen of each animal (6.422 ± 0.416 mg/d). The breath gas sampling system consisted of a 0.5 L stainless steel collecting vessel (canister), a ball-baring inflow restrictor (located just above the animal's nostrils) adjusted to accumulate 0.5 bar of air sample during a 5-day period and a short tube used to connect both. Two collecting canisters were fitted to each animal's head after being evacuated (< 0.5 mb). The breath gas samples were measured over two sub-periods of 5 days during each period (on days 10 to 14 and 16 to 20). Additionally, an identical set, as used with cows, collected background air samples during each 5-day sub-period.

1.3. Statistical analysis: Animal data were analyzed according to a 2 x 2 Latin square design, using the PROC MIXED function of SAS (version 9.1; SAS Inst. Inc., Cary, NC). The production and composition of the milk were analyzed as repeated measures over time, according to an autoregressive model of order 1 (Littel et al. 2000). The pasture data were analyzed according to a 2 x 2 Latin square design by ANOVA using the GLM procedure of SAS. As the interaction treatment x period was not significant, it was not included in the final model. Mean treatment values were compared using the minimum significant difference.

2. RESULTS AND DISCUSSION:

2.1. Sward characteristics and herbage defoliated: Herbage mass above 5 cm (2165 kg DM/ha on average) and sward height (29.5 cm on average) were similar between pastures (Table 1). Botanical composition of both swards was significantly

different, as expected: one with 60% herbage mass of lucerne and white clover and 40% of the grass Bromus auleticus Trin. ex Nees ("cebadilla"), and the other pasture with 24% herbage mass of the legume Lotus corniculatus L. (birds-foot trefoil) and 76% ryegrass. Both swards were in the reproductive stage during the experiment.

Table 1. Biomass, height, botanical, chemical composition of the two experimental swards.

	Pasture treatment		
	Legume	Grass	*P*
Herbage mass[1] (kg DM/ha)	2309	2021	0.2201
Sward height (cm)	31	28	0.5153
Grass / Legume ratio (%DM)	40/60	76/24	<0.0001
Chemical composition[1] (g/kg DM)			
OM	920	903	0.0461
CP	204	102	<0.0001
Condensed tannins	4.6	2.8	0.0205
aNDFom	469	540	0.0260
ADFom	265	312	0.0618
GE (kJ/kg DM)	18.1	16.7	0.0017

[1] Above the motor scythe cutting height (5 cm).

Cows on the grass sward exhibited a higher herbage allowance than in the legume sward, as the area allocated per cow was higher on grass sward (Table 2). However, the depth of defoliation and herbage utilization were similar for both swards. Due to the high herbage allowance per cow, the post grazing height remained substantially higher than the cutting height of the motor scythe, allowing the cows to consume a higher quality of herbage, in particular grass sward.

Table 2. Herbage allowance, depth of defoliation, herbage utilization and chemical composition of the herbage defoliated by grazing dairy cows on pastures rich in legumes or grasses.

	Pasture treatment		
	Legume	Grass	*P*
Herbage allowance[1],[2] (kg DM/ cow/day)	35	45	0.0226
Depth of defoliation (cm)	11	8	0.6436
Herbage utilization[1] (%)	46	37	0.2650
Chemical composition[1] (g/kg DM)			
OM	923	926	0.4481
CP	180	133	0.0225
Condensed tannins	2.2	2.5	0.5119
aNDFom	464	482	0.6946
ADFom	264	259	0.8578
GE (kJ/kg DM)	18.7	19.0	0.5954

[1] Above the motor scythe cutting height (5 cm).
[2] Area allocated per cow: 150 and 225 m^2 on L and G sward respectively

2.2. Herbage intake at grazing and milk production: The OM digestibility of defoliated herbage did not differ between treatments (Table 3).

Table 3. Effect of pastures rich in legumes or grasses on digestibility and intake of herbage organic matter and milk production of grazing dairy cows.

	Pasture treatment		
	Legume	Grass	*P*
Herbage OM digestibility (g/kg OM)	711	704	0.1996
Herbage OM intake (kg/cow/day)	15.9	15.5	0.7558
Fat corrected milk (FCM 4%) (kg/cow/day)	19.9	18.7	0.5173
Fat yield (g/day)	772	711	0.3630
Protein yield (g/day)	699	636	0.3728

Daily herbage OM intake was similar, which agrees with the calculated amount of defoliated herbage presented in Table 2 (herbage allowance x herbage utilization). Fat corrected milk, milk fat and milk protein yields were not affected by the experimental pastures (Table 3). Live weight variation (+ 16 kg LW, on average) was also not affected by treatments. These results are clearly associated with a similar total DOM intake and thus in digestible energy intake, as reported above.

2.3. Methane emission and methane yield: The methane emission was similar among treatments (CV = 13.8%). Methane yield per unit of DMI, and as a percentage of gross energy intake (GEI), did not differ between treatments (Table 4).

Table 4. Effect of pastures rich in legumes or grasses on methane emission and methane yield of grazing dairy cows.

	Pasture treatment		
	Legume	Grass	*P*
Methane emission (L/cow/day)	510	521	0.7237
Methane emission (L/kg FCM 4%)	26.0	28.8	0.3517
Methane yield as %GEI (Ym)	6.4	6.7	0.5971
Methane yield per unit intake (L/kg DMI)	30.2	31.8	0.5821

These values are within the range reported by Boadi *et al.* (2002) and Lassey (2007) for dairy cattle grazing on temperate forages. Ramirez-Restropo and Barry (2005) suggested that feeding forage legumes like lucerne or red clover tends to decrease CH_4 losses (L/kg DMI) compared to grass. Nevertheless, the results of our study do not seem to confirm this. Hammond *et al.* (2009, 2011) recently suggested that methane emissions could relate more to DM intake, which enables variations in the composition of the diet selected at grazing.

CONCLUSION: Estimating methane emission under grazing conditions requires including selective grazing, and consequently, determining the quality of the herbage actually defoliated by grazing animals. This study shows that at a high herbage allowance, the quality of the diet selected by grazing cows did not differ between a pasture rich in grasses and a pasture rich in legumes and as a result, methane emission expressed per unit intake was similar for both swards. Additionally, the multi-day sampling adaptation of the SF_6 tracer technique resulted in values of methane emission agreeing with those reported in the international bibliography for dairy cows where the single-day sampling version of the tracer technique was employed, which may allow for a valuable simplification of experimental logistics.

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EFFECT OF SHORT-TERM PSYCHOLOGICAL STRESS ON SOME PHYSIOLOGICAL INDICES IN RABBITS REARED UNDER DIFFERENT AIR AMMONIA LEVELS: PREVENTIVE EFFECTS OF SUPPLEMENTAL PYRIDOXINE

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ABSTRACT: The objective of the present experiment was to evaluate the effect of air ammonia on several hematological parameters in rabbits and the response to short-term psychological stress, as well as to test the effect of supplemental pyridoxine. Eighteen New Zealand rabbits at the average age of 3.6 months were divided into 3 groups as follows: Control group – reared under low air ammonia levels (6.79±2.55 ppm) and two experimental groups- reared under higher air ammonia levels (21.98±7.84 ppm). The second experimental group was given supplemental pyridoxine (200 mg/l) throughout the 10-day long experimental period. Arterial blood samples were taken at the start (1st day) and end of the experiment (10th day), as well as before and following exposure to psychological stress. Stress was induced on day 10 by 1 minute "dog barking" PC record in a triple 110 dB playback. The following parameters were evaluated: total erythrocyte and leukocyte counts, hematocrit, peripheral blood leukocyte distribution, and ammonia concentration. Ammonia augmented total leukocyte counts ($P<0.05$) and hematocrit levels ($P<0.05$), while at the same time it thwarted the expected rise in heterophil to lymphocyte ratio in response to stress. Pyridoxine prevented ammonia-provoked increase in total leukocyte numbers ($P<0.05$) and hematocrit levels ($p<0.05$) in response to stress. The results are interpreted to suggest that nitric oxide mediates the effects of both ammonia and glucocorticoids on leukocyte subpopulations which ultimately may compromise the effect of glucocorticods on heterophil to lymphocyte ratio.

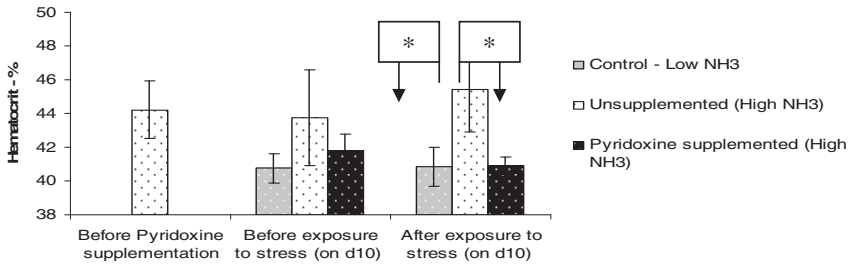
Keywords: rabbits, air ammonia, stress, pyridoxine

INTRODUCTION: Ammonia can reduce the oxygen capture by hemoglobin due to its impact on blood pH (Olanrevaju et al., 2008). Also, the activities of glutathione peroxidase, superoxide dismutase, and catalase decreased in the brains of rats injected with ammonia (Kosenko et al., 1997), thus indicating that ammonia induces oxidative stress. Studies on ammonia-induced changes in hematological indexes are conducted mainly on pigs and poultry (Curtis et al., 1975; Wathes et al., 2004). There is little information about food supplements that antagonize the toxic effect of ammonia in rabbits. Pyridoxine stimulates the production of hemoglobin (Cartwright et al., 1944). Rabbits are known to excrete copious ammount of ammonia via urine. Consequently, we set the target of investigating the effect of ammonia on several hematological indexes. We also studied the possibility to alleviate the adverse effect of ammonia through the supplementation of pyridoxine.

1. MATERIALS AND METHODS: The experiment comprised 18 New Zealand White rabbits (*Oryctolagus cuniculus*) at the age of 3.6 months, divided into three groups (control, unsupplemented and pyridoxine supplemented), consisting of 6 rabbits each. Rabbits in the control group were reared under low air ammonia levels (6.79±2.55 ppm) and the two experimental groups – under high air ammonia levels (21.98±7.84 ppm) of naturally occuring ammonia in the air throughout the experimental period. The second experimental group was given supplemental pyridoxine (200 mg/l) throughout the 10- day long experimental period. Pyridoxine

was produced by Rhône-Poulenc, France. Rabbits were reared in an enclosed building under spring conditions with variable natural temperatures within the range of 9°C to 11°C. They were housed individually in wire-floor cages, provided with feeders and automated drinkers – feed and drinking water were supplied *ad libitum*, except for the pyridoxine supplemented rabbits, which were given supplemental pyridoxine added to the drinking water. Stress was induced by 1 minute "dog barking" PC record in a triple 110 dB playback. Blood samples were taken before and 25 minutes following the start of the stress episode. Total erythrocyte and leukocyte counts were determined by manual haemacytometer chamber count. Haematocrit was measured by the microhaematocrit method. Peripheral blood leukocytes were counted on smears that were prepared immediately after blood sampling. The smears were stained using May-Grunvald and Gisma stains (Lucas and Jambos, 1961). Air ammonia was recorded via AeroQual S200 Monitor, equipted with an ammonia sensor head (0-100±0.1 ppm).The results of one factor statistical analysis are expressed as means±S.E.M. and were analyzed by ANOVA.

2. RESULTS AND DISCUSSION: The hematocrit level in the experimental rabbits increased after exposure to stress and was significantly higher ($P<0.05$) as compared to control and pyridoxine supplemented rabbits (Fig.1) in spite of the unchanged erythrocyte concentration (Fig. 2).



* P<0.05, significantly different from unsupplemented rabbits after stress

Figure 1. Effect of supplemental Pyrodoxine (200 mg/L) on ammonia - induced change in hematocrit level after stress.

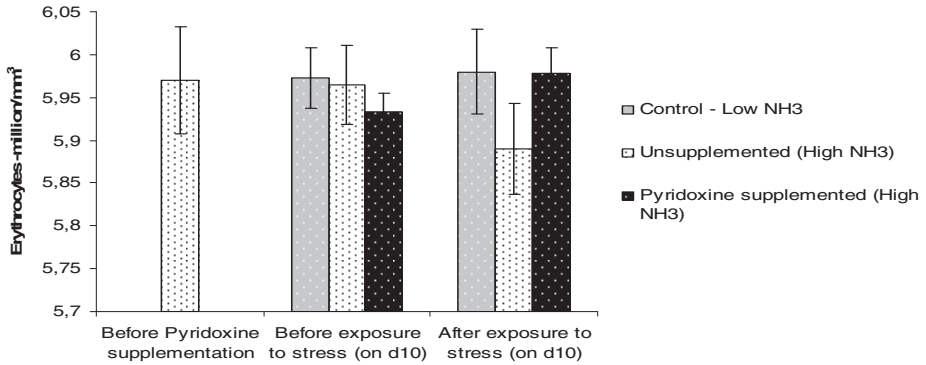
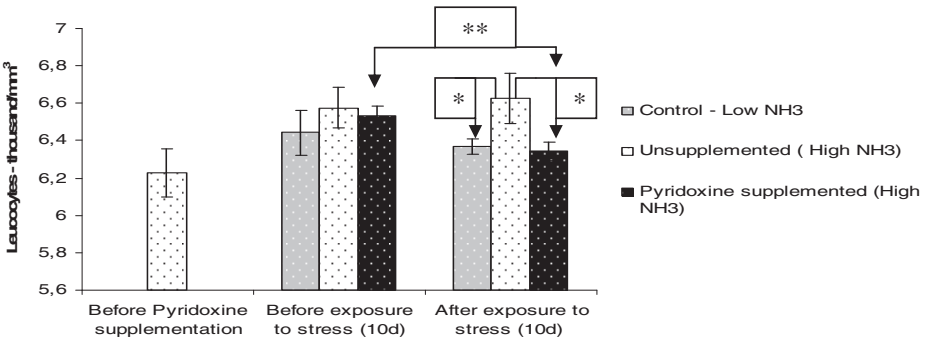


Figure 2. Erythrocyte concentrations before and after short-term stress in Pyridoxine supplemented and unsupplemented rabbits reared under low and high ammonia levels.

The increase of hematocrit in unsupplemented rabbits following exposure of rabbits to psychological stress (Fig. 1) appears to be an adaptive response to the increased oxygen demand caused by increased metabolism. The lower hematocrit level in pyridoxine supplemented rabbits following exposure to physiological stress (Fig.1) may be due either to the beneficial effect of pyridoxine on erythrocyte membrane function or to its regulatory role in Na^+/K^+ ATP ase and cellular volume (Nadiger et al., 1984). Exposure to psychological stress resulted in significant increase of WBC in unsupplemented rabbits relative to control and pyridoxine supplemented rabbits (Fig.3).



* P<0.05; ** P<0.01

Figure 3. Leucocytes concentrations before and after short-term stress in Pyridoxine supplemented and unsupplemented rabbits reared under low and high ammonia levels

Glucocorticoids play a certain role in the maintenance of leukocyte counts (Deutsch et al.,2007), but it seems that ammonia might have prevented or changed the expected effect of glucocorticoids on WBC, as judged by the unchanged heterophil to lymphocyte ratio after the rabbits' exposure to stress. Lymphocyte and heterophil percentages in all groups were not changed after exposure to stress (P>0.05). We hypothesize that glucocorticoids exert their effect on leucocyte distribution by suppressing NO synthesis (Korhonen et al, 2002). Ammonia unlike glucocorticoids stimulates NO production (Swamy et al., 2005) and therefore could compromise stress-induced increase in the heterophil to lymphocyte ratio. Pyridoxine prevented ammonia-induced changes in hematocrit and WBC. The observed effect of pyridoxine could be ascribed to its beneficial effect of erythrocyte membrane Na^+ K^+ ATPase activity (Nadiger et al., 1984), which ultimately may lead to improvement of the oxygen-carrying capacity of the blood.

CONCLUSION: High ammonia concentrations elevated WBC and hematocrit after exposure to psychological stress. These effects of ammonia were prevented by supplemented pyridoxine.

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AMMONIA AND GREENHOUSE GAS EMISSIONS FROM DAIRY CATTLE BUILDINGS: SLURRY VS. FARMYARD MANURE MANAGEMENT SYSTEMS

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ABSTRACT: Dairy cattle buildings represent a large portion of agricultural emissions in Europe. French specificity resides in high proportions of dairy buildings including straw- based deep litter. Because little is known about emissions from these systems, the aim of our experiment was to compare gas emissions from two contrasted manure managements in controlled conditions: a tie-stall (TS) producing slurry and a straw-based deep litter (DL) producing farmyard manure. Two groups of three dairy cattle were offered both treatments in a Latin-square design during two periods of six weeks. Mean daily emissions were 78 %, 33 %, 25 % and 85 % higher for DL compared to TS, respectively, for C-CO_2, C-CH_4, N-NH_3 and N-N_2O. These emissions were high compared to the literature, which could be partly due to overestimation of ventilation rates and/or polluted air entering the rooms through gutters. CH_4 and N_2O emissions from DL increased throughout accumulation time because of anaerobic conditions. At the end of the experiment, without animals and new fresh manure input, emissions from the litter alone rapidly decreased. These results contribute to a better understanding of emissions from two contrasted housing systems representative of French conditions.

Keywords: dairy cattle, gas emissions, housing, slurry, farmyard manure

INTRODUCTION: Since ammonia (NH_3) and greenhouse gas (GHG) emissions from livestock contribute substantially to environmental pollution, all possible sources must be quantified and reduced. Among them, dairy cattle buildings represent a large part of agricultural emissions in Europe. French specificity resides in its great diversity of housing systems, with more than 50% of dairy buildings including straw-based deep litter. Because little is known about polluting emissions from these systems, the aim of our experiment was to compare NH_3 and GHG emissions from two contrasted manure managements in controlled climatic rooms: a tie-stall (TS) producing slurry and a straw- based deep litter (DL) producing farm yard manure (FYM).

1. MATERIAL AND METHODS:

1.1. Experimental design: Experiments were performed at the INRA experimental farm in Méjusseaume (Brittany, France) in autumn 2010. Two groups of three dairy cattle (650kg) in late lactation were offered both TS and DL housing systems (in 15-25°C mechanically ventilated climatic rooms) in a Latin-square design during two periods of six weeks. TS manure was collected in a gutter and scraped twice a day. For DL, fresh straw was added daily (10-15kg/cow/day) and liquids were collected in a gutter. Animals were fed a mixed diet of maize silage (83%) and soybean meal (17%) and had a permanent access to water. Individual milk yield and dry matter

(DM) intake were recorded daily. Samples of feed, milk and all types of dejection were analyzed for chemical composition.

1.2. Ventilation and gas measurements: Ventilation rates were estimated throughout the experiment by using the gas (SF_6) tracer method (Phillips et al., 2000). Gas concentrations (H_20, NH_3, CO_2, CH_4, N_20 and SF_6) were measured continuously with an infrared photo-acoustic gas analyzer (INNOVA 1412). Emissions were the result of the product between ventilation rates and the difference between inlet and outlet gas concentrations, and were validated through element mass balances at the system level.

It appeared that the configuration used for the gas analyzer led to strong interferences between ammonia and volatile fatty acids and alcohols emitted by maize silage. This caused large peaks of NH_3 concentration during feeding phases (Hassouna et al., 2012). Therefore, we decided to correct overestimated ammonia emissions by suppressing these peaks. The subsequent NH_3 emissions are consequently potential ones.

2. RESULTS AND DISCUSSION: Ventilation flows were 950 ±10 m^3/h/cow, similar to naturally ventilated buildings in France (1000 m^3/h/cow, Dollé and Robin, 2006). CIGR equations, based on animals' heat and CO_2 productions (Pedersen and Sällvik 2002), predicted an air flow rate of 650 m^3/h/cow (68% of the measured value). Obviously, both methods are associated with high uncertainties. Samer et al. (2012) stated that the CO_2 balance method has several error sources in the calculation process (e.g. CO_2 produced per energy unit, amount of CO_2 emitted from manure and location of CO_2 sampling points). The resulting relative error could vary within 2-50% of the actual values (Ngwabie et al., 2011). The tracer gas method can also result in bias depending on injection and sampling points' location and tracer gas recovery rate (Scholtens et al., 2004). In the present study, climatic rooms were maintained under-pressure (to avoid leakage) and SF_6 was directly sampled in the exhaust air to maximize recovery.

Table 1. Emissions of contrasted manure management systems (DL = deep litter, TS = tie-stall) and the difference between both attributed to litter emissions.

System	C-CO_2 g/d/LU*		C-CH_4 g/d/LU		N-NH_3 g/d/LU		N-N_2O g/d/LU	
	Mean	Se	Mean	Se	Mean	Se	Mean	Se
TS	3861	54	373	6	37.4	1.2	0.36	0.02
DL	6876	231	495	12	46.2	1.7	0.67	0.07
DL-TS	3015		122		8.8		0.31	

* LU = 500kg live weight

Mean daily emissions were 78 %, 33 %, 25 % and 85 % higher for DL compared to TS, respectively, for C-CO_2, C-CH_4, N-NH_3 and N-N_2O (Table 1). Data from TS systems are scarce in the literature and lower than our results. Powell et al. (2008) measured 7-16 gN-NH_3/d/LU from tie-stall dairy experimental chambers in similar conditions (16-24°C; controlled ventilation: 300-800 m^3/h/cow). Regarding CH_4, a large majority is believed to originate from enteric fermentations. From Vermorel (1995), CH_4 enteric emissions from 650 kg live weight cattle fed on maize silage and producing 20 kg of milk should be 500 l CH_4/d/cow, which is 270 g C-CH_4/d/LU when we measured 373 g C-CH_4/d/LU. Studies reporting emissions from dairy cattle housed on deep litter (DL) are even more limited. Mosquera et al. (2006) recorded 23 gN-NH_3/d/LU and 563 gC-CH_4/d/LU (estimated live weight of 600 kg) from a naturally ventilated building (765 m^3/h/cow, 7.5 °C). In their study, bedding (FYM)

was accumulated for long periods (removed once or twice a year), which can explain why methane emission is higher.

C-CH_4 and N-N_2O emissions from the litter itself (DL – TS) increased throughout accumulation time (Figure 1). This could be due to anaerobic conditions and increased temperatures due to fermentation in the litter, creating optimal conditions for microbial metabolism and denitrification processes (Chadwick et al., 2011).

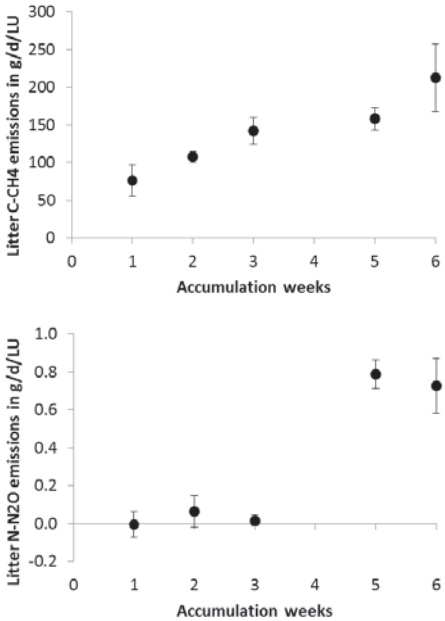

Figure 1. Litter C-CH_4 (left) and N-N_2O (right) emissions (DL-TS) through accumulation time (mean and standard error of the daily differences for each week). No measurement for week 4 because of analyzer dysfunction.

Element mass balances are presented in Table 2 for TS (more variable for DL because of litter samples unrepresentative of the whole period). Except for phosphor, mass balances were satisfying (errors < 11 %). As the large majority of P excretion takes place in feces, the underestimation of P outputs in period 2 might be explained by unrepresentative sampling of the collected feces (inputs being the same as in period 1). Carbon and nitrogen outputs seemed overestimated whatever the period (5-11%). This corroborates the hypothesis of overestimated emissions due to high ventilation rates. However, if estimated flow rates from CIGR were used for emission calculation, water, carbon and nitrogen mass balances would fall to 83-89%. Another hypothesis could come from polluted air entering the rooms (underpressure) from slurry gutters connected to the pit. This could lead to overestimation of inside gas concentrations and consequently to higher emissions. Before the start of the experiment, emissions measured without animals reached 357 gC-CO_2/d/LU, 34 gC-CH_4/d/LU and 9 gN-NH_3/d/LU (0 gN-N_2O), respectively, 9, 9 and 24% of TS emissions (Table 1). More care should be taken in preventing polluted air to enter the room as it can have non-negligible consequences on emission estimations.

At the end of the experiment, daily emissions from the litter alone (expressed per LU to enable comparisons) averaged 2000 g C-CO_2, 38 g C-CH_4, 10 g N-NH_3 and

0.93 gN-N_2O. Without new input of N and C elements from fresh manure, emissions from the FYM rapidly decreased to a level close to storage conditions (Mosquera et al., 2006).

Table 2. Element mass balances presented as the ratio between output and input (%) at the system level and for each period of 6 weeks for the tie-stall (TS) system.

Element	Water output / input %	Carbon output / input %	Nitrogen output / input %	Phosphor output / input %	Potassium output / input %
Period1	104	111	107	95	107
Period2	96	107	105	76	97

CONCLUSION: When compared to similar conditions, GHG emissions were higher for a deep litter than for a tie-stall system, suggesting high emissions from the FYM due to anaerobic conditions. These results contribute to a better understanding of emissions from two contrasted housing systems representative of French conditions.

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AMENDMENT OF BIOCHAR TO SLURRY: A POSSIBILITY TO MITIGATE AMMONIA EMISSIONS

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ABSTRACT: Amendments of biochar (BC) to slurry potentially reduces NH_3 losses in animal housing and during storage. In this study, we report on an investigation on the effect of adding biochar to slurry during storage.
Two untreated biochars, with strong alkaline (BC22) and neutral (BC24) pH respectively, and one acidified biochar (BC24 treated with a phosphoric acid solution) are added to fresh slurry from dairy cows. Ammonia emissions are measured using a Dynamic Chamber system in conjunction with an HT-CIMS and a Cavity Ring down NH_3 analyzer.
The addition of the untreated biochar alters the ammonia emission in both directions (BC24 to roughly 75% – 100% and BC22 to roughly 95% – 105% of the control sample), whereas the acidified biochar significantly reduces emissions (< 3% of the control sample).
The results indicate that not the pH of BC alone, but a combination of BC characteristics influences the ammonium adsorption potential of untreated biochar.

Keywords: NH_3, slurry, cattle, storage, mitigation strategy

INTRODUCTION: Biochar, a pyrolysis product of organic material, is an amendment for agricultural systems to improve soil fertility, sequester CO_2 and reduce greenhouse gas emissions (Lehmann and Joseph, 2009; Clough and Condron, 2010; Atkinson et al., 2010). It is an efficient adsorbent for NH_3 in the gas phase (e.g. Asada et al., 2002; Asada et al., 2006; Iyobe et al., 2004). Further, when added to composting material, BC lowers ammonia emissions (Steiner et al., 2009; Chen et al., 2010; Hua et al., 2008), and Taghizadeh-Toosi et al. (2011) found that BC, incorporated into soil, reduces the NH_3 cumulative loss after urine application. We focus on NH_3 emission reduction during slurry storage and do not consider potential later losses/consequences.

1. MATERIAL AND METHODS: Measurements were performed using two different types of BC (Table 1). BC24, a pyrolysed mix of 20% hardwood and 80% softwood, with a neutral pH, and BC22, which originates in sieve residues from forest material, and is alkaline with a relatively high pH of 12.4. Both BC were stored for one year before measurements. In an initial measurement series (V1), the effect of the addition of the two untreated biochars, BC22 and BC24, was compared to a slurry control sample. In a second series (V2), BC24 was acidified with phosphoric acid by soaking in 5% orthophosphoric acid solution for 5 days. This acidic biochar (PSBC24) was compared to the untreated BC24 (BC24-2), the same amount of acid was added to the control sample (PS), and a slurry control sample (Control-2). For each sample, a 6L bucket with 5L of dairy cow slurry was used. BC was added to the BC samples and mixed for 2 min (with a kitchen mixer) immediately before the experiment started. Each BC sample contained 200 g of biochar.

Table 1. Elementary composition, BET surface area (N_2 adsorption) and pH of the investigated BC. (20L80N: 20% hard-/80% softwood. SR-W: sieve residues forest).

	Material	C (g/kg)	N (g/kg)	O (g/kg)	H (g/kg)	BET SA (m^2/g)	pH (in $CaCl_2$)
BC24	20L80N	799.2	4.6	89.2	18.9	109	7.0
BC22	SR-W	767.2	6.4	62.0	6.3	123	12.4

The slurry was collected directly from the stable and stored at 4°C until the start of the measurements. Before the experiments started, the slurry was diluted with water at a ratio of 1:2, slurry to water. Table 2 gives the characteristics of the control slurries.

Table 2. Characteristics of the dairy cow slurry for the two measurement series V1 & V2. (OM: Organic Matter. TAN: total ammoniacal nitrogen).

	DM (g/L)	Ash (g/L)	OM (g/L)	N_{tot} (g/L)	P_2O_5 (g/L)	KO_2 (g/L)	Ca (g/L)	Mg (g/L)	Na (g/L)	TAN (g/L)	Density (g/L)	pH
V1	59.1	15.9	43.2	2.79	1.15	3.07	1.12	0.53	0.33	1.33	1020	7.1
V2	58.7	15.8	42.9	2.86	1.10	3.07	1.02	0.50	0.36	1.45	1020	6.7

The measurements were performed using a Dynamic Chamber (DC) system (Pape et al., 2009) in a large environmental chamber with regulated temperature and humidity. Both temperature and humidity were held constant at 20°C and 60%, respectively. The ingoing concentration of the DC was measured with a Cavity Ring-Down spectrometer, the outgoing concentration was measured with a HT-CIMS (Sintermann et al, 2011). The inflow to the DC was held constant at 60 L/min. The samples were measured in turn, for approximately one hour each. Before the samples were placed in the DC for emission measurements, they were mixed for 2 min. In between measuring intervals, the samples were stored in a separate environmental chamber at the same temperature and relative humidity.

2. RESULTS AND DISCUSSION: Flux measurements in a Dynamic Chamber reflect a potential emission flux due to the high air exchange rate and the enhanced turbulent transport from the slurry surface. This flux will exceed the effective flux from a storage system. Flux measurements did not show major enhancement in the average NH_3 emissions due to the BC addition (Figure 1), as might have been expected from the pH characteristics of the BCs. When adding BC24 to slurry, there was even a small 5-10% reduction compared to the control sample. N-Budget calculations (covering 20 days of slurry storage) supported these findings in emission reduction due to the BC addition for both BC types. For the acidified BC and the direct amendment of acid, the reduction was almost 100%, due to the very low pH established in the samples. Integrated over the entire observation time, the acid only was the most effective mitigation strategy, acting in high ambient concentration periods even as a sink for ammonia. The addition of acidified BC resulted in higher, although still very low, emissions of NH_3.

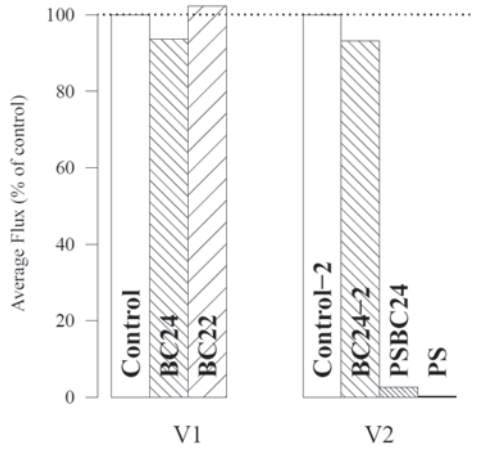

Figure 1. Overall average of the measured flux in % of control sample. (measurement series V1 & V2).

Figure 2 shows the average measured flux for the 8 measuring events in series V1. The absolute NH_3 emission decreased from roughly 200 µg m^{-2} s^{-1} in the first event, to about 90 µg m^{-2} s^{-1} in the last event. This decrease in the flux parallels with a decrease in slurry pH from 7.9 to 6.9 in all the samples. The temporal dynamics of the emission reduction is characterized by a higher reduction at the beginning of the experiments (measuring event 1 and 2) and a decreasing reduction after a few days of storage.

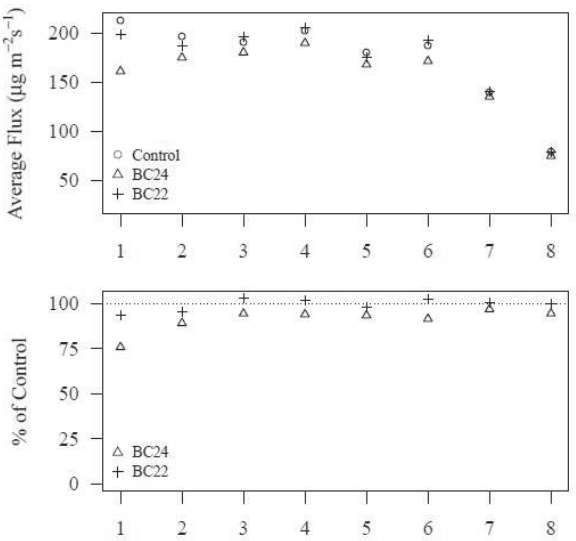

Figure 2. Measured average flux. Absolute (top) and relative to control sample (bottom). (8 measuring events in measurement series V1).

CONCLUSION: Amendment of BC to slurry during storage may reduce ammonia emissions, depending on the characteristics of the BC added. The reduction in NH_3 loss mainly occurs directly after adding BC to the slurry. The results of this study indicate that not the pH of BC alone, but an interaction of BC characteristics determines its ammonium adsorption potential. This indicates that a variety of NH_3

emission reduction behaviors can be expected depending on the source material, the pyrolysis process and the post-treatment of the biochar.

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AIR QUALITY IN ALTERNATIVE LAYER SYSTEMS AS AN INDICATOR OF HEALTH EFFECTS

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ABSTRACT: Since January 2012, the European community banned cages for keeping layers; however, some countries will not follow now or in the immediate future. Various reasons exist for postponing compliance. One reason may be lack of knowledge concerning possible effects of alternative systems on nearby residents, as well as on birds and farmers inside the stables.
Concentrations of airborne contaminants are used as an indicator for air quality inside the stable. These will be compared with available limit values. Furthermore, fine dust concentration was calculated according to the Johannisburg convention to more closely correspond with former investigations.
Stables of commercial farms and research facilities, aviaries, floor keeping and the German small group housing system were investigated.
NH_3 and CO_2 were measured with gas monitors. Dust concentration was evaluated with optical particle spectrometers and pycnometers for physical density. Measurements were performed online at a representative central location at 1.5 m height over 1h, 24h or 48h, depending on the task and the stable conditions.
Ammonia concentration ranged between 1 ppm and 30 ppm with no typical daily courses. A strong influence of manure belt cleaning was observed. The limit of 20 ppm was exceeded for only several samples. CO_2 was always below 3,000 ppm.
PM_4 ranged from less than 0.1 mg/m³ up to peaks with 8 mg/m³. On average, the 3 mg/m³ limit was maintained. PM showed a typical course of day and night time, depending on the birds' activity.
For all contaminants, the small group keepings showed the lowest values.

Keywords: layer, ammonia, carbon dioxide, dust, manure strategy

INTRODUCTION: Since January 2012, the European community banned cages for keeping layers. Germany already achieved the concerned directive in 2010. Other member states must now follow; however, some countries will not follow now or in the immediate future. Various reasons exist for postponing. One reason may be lack of knowledge concerning possible effects of alternative systems on nearby residents, as well as on birds and farmers inside the stables.

This paper will contribute to the last item using air quality inside the stable as an indicator for health and welfare by measuring concentrations of gaseous and particulate airborne contaminants. Ammonia, carbon dioxide and respirable dust (PM4) are the focus. Additional to PM_4, fine dust concentration was calculated according to the Johannisburg convention to more closely correspond with former investigations.

The concentrations are compared with given or expected limit values defined by occupational or veterinary medicine. In particular, this means that limits of 20 ppm for ammonia, 3,000 ppm for carbon dioxide and 3 mg/m³ for PM4 indicate sufficient air quality in the stable.

1. MATERIALS AND METHODS: The measurements are part of three projects in different layer systems from which one is completed (cf. Hinz et al. 2009 and Winter et al. 2009). Stables were investigated on commercial farms, research facilities,

aviaries, floor keeping and the small group housing system (a German development). The number of birds varied from approximately 1,500 birds up to more than 90,000 birds. All stables were equipped with force ventilation systems and an artificial light program. In aviaries (A) and small group housing systems (SG) ventilated or non-ventilated manure belts were used at distinct time-intervals to keep the air in the stable clean from ammonia. The number of cleaning procedures per week depends on the farm management, as is the use of litter.

NH_3 and CO_2 were measured with an opto-acoustic gas monitor Innova 1302. Dust concentration was evaluated with Grimm 1.108 optical particle spectrometers for size and number concentration. Related to human health, the respirable fraction is most interesting, which is defined according to EN 481 and differs from the previously used fine dust definition with range and shape of the function. Both definitions are applied to measured particle size distribution. Calculating the resulting mass requires knowing physical density. It was determined with a 50 mL pycnometer from samples collected from dust settled on surfaces in the stable or airborne dust gathered by a high volume sample with a cyclone separator. Knowing that the density of particles from dust in animal houses increases for smaller particles, for mass calculation, a mean value for a fraction < 28 µm was used. For this purpose, all dust samples were sieved to this mesh size. All measurements were performed online at a representative central location in the stable 1.5 m over the floor for durations of 1h, 24h or 48h, depending on the task and the stable conditions. Dust samples were taken with a 1.25 m/s sucking velocity.

2. RESULTS AND DISCUSSION: Ammonia concentration ranged between 1 ppm and 30 ppm, with no typical courses for day and night, depending on the housing system. However, through the strong influence of manure belt cleaning, one must distinguish between days with and without manure belt cleaning, demonstrated with the example of three SG housings in Figure 1.

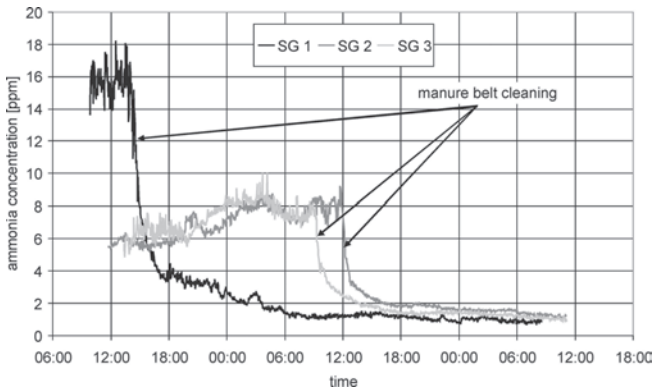

Figure 1. Courses of ammonia concentrations in 3 small group housing systems on days without and with manure belt cleaning.

Manure belt cleaning leads to a sharp sustainable effect of decreasing ammonia concentration. A ratio of maximum to minimum concentration up to a factor of 8 can be observed. The quasi periodic cleaning procedure leads to significant weekly courses of the ammonia concentration, which are similar to a saw tooth function with a periodicity according to the number of cleaning operations, as given in Figure 2.

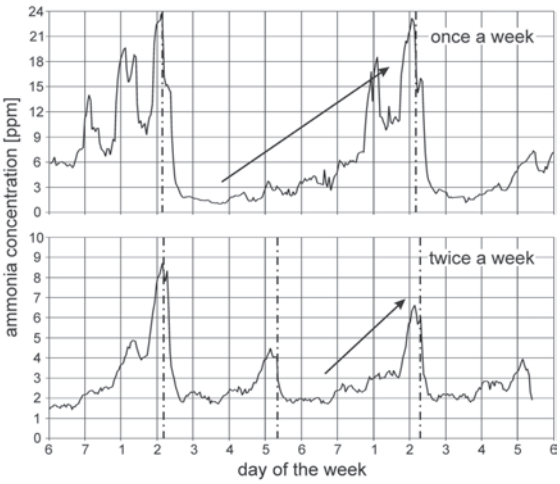

Figure 2. Ammonia concentration in two small group housing systems with manure belt cleaning once and twice a week.

The concentration of carbon dioxide is a further indicator of air quality inside stables. In contrast to ammonia, no specific effects were observed apart from the ventilation strategy. In all investigations the mean CO_2 concentration was below 3,000 ppm.

The respirable fraction PM_4 ranged from less than 0.1 mg/m³ up to peaks with 8 mg/m³. On average, the limit of 3 mg/m³ was maintained. PM showed a typical course of day and night time depending on the birds' activity influenced by the light program. In Figure 4 daily courses of PM4 are indicated for three aviaries.

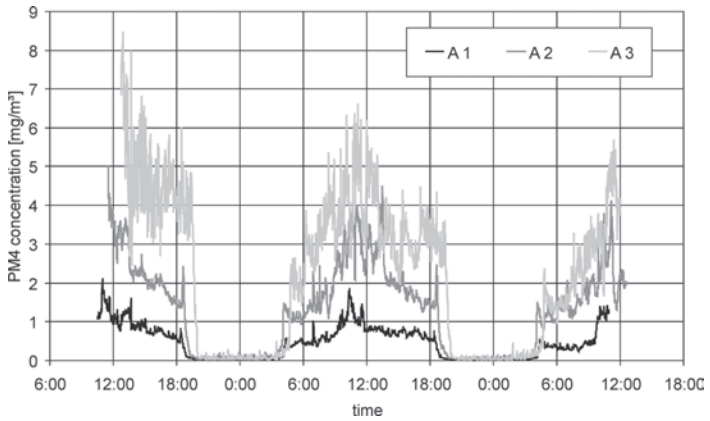

Figure 3. Daily courses of PM_4 in three aviaries

To correspond with earlier studies, it must be mentioned that fine dust followed the definition of the separation function $T = 1-(d/7.07)^2$, where d is the particle diameter in µm. This fine dust fraction may be called PM_5, because the 50% cut point is given for 5 µm particles. This use of the definition leads to values which differ from the EN 481 definition by 25%, on average. Table 1 gives the results for different housing systems as ratio PM_5/PM_4.

Table 1. Results of PM5/PM4 ratio.

System	maximum	minimum	average
floor keeping with outdoor access	1.29	1.22	1.26
Aviary	1.29	1.16	1.26
floor keeping	1.29	1.20	1.27
German small group housing	1.27	1.22	1.26

CONCLUSION: Concentrations of airborne contaminants can be used as indicators for air quality in animal houses with regard to individual health and welfare. For the investigated different layer housing systems, the daily averages of PM_4, NH_3 and CO_2 maintained the given limit values of 3 mg/m³, 20 ppm and 3000 ppm, respectively.

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IMPROVED ASSESSMENT OF AMMONIA EMISSION FACTORS FOR FIELD-APPLIED MANURE, FERTILIZERS AND GRAZING IN THE NETHERLANDS

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ABSTRACT: Additional data and improved methods are presented for estimation of ammonia (NH_3) emission factors (EF) for field-applied liquid manures, fertilizers and droppings of grazing cattle in the Netherlands. The EFs are for manures expressed in % of the total ammoniacal nitrogen (TAN) applied and for fertilizers in % of the total N applied. For field-applied liquid manure, EFs were derived from NH_3 emission measurements on grassland and arable land in the Netherlands. For manure application on grassland, the current EF estimates are 74% for broadcast surface spreading, 26% for narrow band application and 19% for shallow injection. The EF for shallow injection increased significantly over the past years. Estimates for arable land are 69% for broadcast surface spreading, 22% for direct surface incorporation and 2% for deep placement. The EFs for the major fertilizer types used, specified for soil type and land use, were calculated with the empirical model of Bouwman et al. (2002). The estimated EFs ranged from 0% for nitrate fertilizer to 14.3% for urea. The EF for the most commonly used fertilizer, calcium ammonium nitrate, was 2.5%. The revised EF for grazing reflects the effects of changed fertilizer application rates and subsequent effects on N content of the feed intake and excreted TAN, the changed grazing method and soil type. The mean EF for grazing in the Netherlands was 7.2% of excreted TAN in 1992 and 2.7% in 2009.

Keywords: ammonia emission, manure application, fertilizer, grazing

INTRODUCTION: To protect the environment, the European Union prescribes national emission ceilings for NH_3. Velthof et al. (2011) developed a new NH_3 inventory model for national emission registration in the Netherlands (NEMA). The NH_3 emission from each source is described by an emission factor (EF). For manures the EF is expressed in % of the TAN applied and for fertilizers in % of the total N applied. This paper concerns the revision of EFs of liquid manure application, fertilizer application and manure deposited by grazing cattle.

1. MATERIAL AND METHODS:

1.1. Manure application: Based on NH_3 emission experiments until 1997, Huijsmans et al. (2001, 2003) reported EFs for liquid manure application techniques: broadcast surface spreading, on grassland with narrow-band application and shallow injection, and on arable land direct surface incorporation and deep placement. These EFs needed revision because 89 additional experimental data after 1997 were available for grassland. Statistical estimation of EFs needed adaption for use in NEMA, and the EF for shallow injection seems increased since the start of measurements in 1989. The total number of observations is given in (Table 1). For each application method, the EF was initially calculated as the mean of all available total emission data. The significance of possible changes in emission over the years was tested by adding the number of years since 1988 for each experiment as an explanatory variable to the

statistical models of Huijsmans et al. (2001, 2003). In case the effect of the time lapse since the start of the experiments was significant, the current EF for the manure application method concerned was estimated by fitting a curve through the data over the years.

1.2. Fertilizer application: Field data on NH_3 emission after fertilizer application in the Netherlands are insufficient to derive EFs. Therefore, the EFs for average conditions in the Netherlands were based on analysis of international data for fertilizers and the derived statistical model by Bouwman et al. (2002). This model estimates NH_3 emission from fertilizers, based on crop type, fertilizer type, Cation Exchange Capacity (CEC) of the soil, application mode, N application rate, climate and soil properties.

1.3. Grazed grassland: Based on the results of Bussink (1992, 1994), a fixed EF of 8% of total N for grazing was used until recently. The current EF for grazed grassland should be lower due to decreasing N application rates, and the subsequently lower N content of grass intake. A new method was used to estimate the EF for grazed grassland. The data by Bussink (1992, 1994) were reprocessed to correct for the NH_3 emission caused by the applied fertilizer, to correct for the change from continuous to restrictive grazing, and to derive an empirical model to estimate the EF for grazing in dependence of the feed N content and the CEC of the soil.

2. RESULTS AND DISCUSSION:

2.1. Manure application: The EFs for manure application methods for grassland and arable land are presented in Table 1. Only for shallow injection, the analysis of trends in the data over time, since the start of the experiments, revealed a statistically significant ($P < 0.01$) increase of both the total NH_3 emission and the volatilization rates on grassland. The increase in emission was not caused by possible changes of manure characteristics and application rate, wind speed, temperature, relative humidity, incoming radiation and soil type since the start of the experiments. The current EF for shallow injection on grassland (Table 1) was estimated at 19%. It is suggested that the increase in NH_3 emission over the years may have been caused by a decrease in injection depth.

Table 1. Number of observations (n), emission factors EF (in % of TAN applied) and range in the data for various liquid manure application methods.

Manure application method		n	EF (%)	Range
Grassland	Surface spreading	81	74	28-100
	Narrow band	29	26	9-52
	Shallow injection, (average)	89	16	1-63
	Shallow injection, (current)		19	-
Arable land	Surface spreading	26	69	30-100
	Surface incorporation	25	22	3-45
	Deep placement	7	2	1-3

2.2. Fertilizer application: Main factors affecting the NH_3 emission from fertilizers in the Netherlands are land use, fertiliser type, pH of the soil and CEC of the various soil types. Bouwman et al. (2002) distinguish land uses as “grassland” and “upland crops” and various pH classes of the soil. Arable land and maize land were defined as “upland crop”. For the Netherlands, low $CaCO_3$ ($pH < 7.3$) and rich $CaCO_3$ (calcareous) soils ($pH > 7.3$) were distinguished using the soil map, which showed

that 13% of grassland soils, 9% of maize land, and 49% of arable land are calcareous. Of all agricultural land, 24% is calcareous. To match the categories with the pH categories of Bouwman et al. (2002), it was assumed that half of the low $CaCO_3$ soils had a pH lower than 5.5, and the other half had a pH of 5.5-7.3, and the calcareous soils had a pH of 7.3-8.5. Based on soil analytical data over the 2007-2008 period, mean CEC was 70 $mmol_c\ kg^{-1}$ for sandy soils, 180 $mmol_c\ kg^{-1}$ for clay and loess soils and 300 $mmol_c\ kg^{-1}$ for peat and reclaimed peat soils. Based on the relative areas of the soil types in the Netherlands, the area weighted CEC for grassland was 146 $mmol_c\ kg^{-1}$ and for arable land 134 $mmol_c\ kg^{-1}$. Using these estimates, the EFs of various fertilizer types used in the Netherlands were derived for the weighted areas of land use, soil pH and CEC of various soil types (Table 2).

Table 2. Average emission factors (EF, in % of N applied) for the major fertilizers in the Netherlands, calculated with the method by Bouwman et al. (2002).

Fertilizer type	EF	Fertilizer type	EF
Ammonium nitrate	5.2	NP fertiliser	7.4
Ammonium sulphate	11.3	NPK fertiliser	7.4
Calcium ammonium nitrate	2.5	Urea	14.3

2.3. Grazed grassland: The data by Bussink (1992, 1994) for continuous grazing on calcareous soil include the NH_3 emission of applied mineral fertilizer (Table 3). After correcting for the mineral fertilizer, the EFs for the excreta produced during grazing were calculated at 3.3-9.7% for continuous grazing. Currently, grazing is mostly restricted to daytime in the Netherlands. Based on measured emission fluxes of Bussink (1992), for continuous and restricted grazing it was estimated that restricted grazing results in a 1.2 times higher EF than continuous grazing, resulting in EFs for restricted grazing of 4.0-11.7%. From the experimental data, the following empirical relationship between measured N content in the feed and NH_3 emission could be derived for restricted grazing on calcareous soil:

$$EF_{grazing} = 1.33*10^{-5} * N_{feed}^{3.66}\ (R^2 = 0.90),$$

with $EF_{grazing}$ the emission factor (% of the TAN-excretion) and N_{feed} the N content of the feed intake during grazing (in g N kg^{-1} DM). For other soil types with different cation exchange capacity (CEC), $EF_{grazing}$ can be estimated by multiplying by a factor CEC_{corr} according to Bussink (1996): CECcorr= (7.71-0.02793*(CEC-280))/7.71. For the Netherlands, CEC correction factors are, respectively, 1.8 for sand, 1.4 for clay or loess and 0.9 for peat or reclaimed peat. Analytical data of grass samples showed that N_{feed} has decreased markedly from 32.9 to 25.2 g N kg^{-1} dry matter (DM) in the 1992-2009 period, corresponding with an estimated drop in EF from 7.2 to 2.6%. As the current N_{feed} is already in the extrapolated area of the empirical expression for $EF_{grazing}$, it is suggested to fix the $EF_{grazing}$ to 2.6% for $N_{feed} < 25$.

Table 3. Emission factors for grazing on calcareous soil based on Bussink (1992, 1994).

	Experiment year					
	1987	1988	1988	1990	1990	1990
kg fertilizer N ha^{-1} $year^{-1}$	550	250	550	250	400	550
N-content feeding, g kg^{-1}	42.0	33.5	41.1	31.0	38.7	39.5
fraction N excreted at measuring plot *	0.92	0.92	0.92	0.88	0.86	0.88
TAN (urine) excreted, kg N ha^{-1}	425	203	428	217	339	407
measured overall NH_3 emission, kg N ha^{-1} **	42	8	39	9	27	33
Correction NH_3 emission fertilizer, kg N ha^{-1} ***	4	2	4	2	3	4
NH_3 emission continuous grazing, kg N ha^{-1}	38	6	35	7	24	29
EF (continuous) grazing, % of TAN excreted ****	9.7	3.3	8.9	3.7	8.2	8.1
EF restricted grazing, % of TAN excreted *****	11.7	4.0	10.7	4.6	9.9	9.6

* excluding excretion during milking. ** reported by Bussink (1992, 1994). *** = 0.75*0.01*fertilizer applied (only 75% of fertilizer applied during experiment, NH_3 emission 1%). **** calculated as fraction of TAN excreted at measuring plot. ***** calculated as 1.2*NH_3 emission for continuous grazing.

CONCLUSION: The emission factor for shallow injection of liquid manure on grassland increased to 19%, probably due to a decrease in depth of injection. Estimated current EFs for liquid manure application on grassland are 74% for surface spreading, 26% for narrow band application and 19% for shallow injection, and on arable land 69% for surface spreading, 22% for shallow incorporation and 2% for deep placement. The estimated EFs for application of fertilizers are now specified for the various types of fertilizer, soil types and land use in the Netherlands. The mean EFs, weighted for soil type, ranged from 2.5% for the most commonly used N-fertilizer, calcium ammonium nitrate, to 14.3% for urea. The estimated EFs for manure deposited by grazing cattle in the Netherlands are 7.2% of excreted TAN in 1992 and 2.7% in 2009, due to changes in management of grazing and fertilizer input.

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DAILY VARIATIONS OF DUST CONCENTRATION IN THE AIR OF POULTRY HOUSES FOR LAYING HENS

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ABSTRACT: High concentrations of aerial dust occur in poultry houses for laying hens and may cause adverse effects on animal health and on the respiratory health of farmers and nearby residents. A descriptive study was established to identify rearing and ventilation management practices influencing ambient dust concentration during a day in poultry houses for laying hens. Dust concentration was monitored during 24 hours in 8 caged poultry houses and 7 on-floor poultry houses. Respirable dust (diameter < 5 μm) concentration was measured every 15 minutes with a laser photometer. Data on poultry buildings, ventilation regulation, husbandry conditions and farmer activities during the day of measurement were collected. A higher and more variable dust concentration was observed in on-floor buildings (mean: 0.848 mg/m^3 IC95% [0.774-0.894]) than in caged buildings (0.429 mg/m^3 IC95% [0.409-0.449]). Ambient dust concentration positively correlated to temperature inside the building and negatively to relative air humidity. Both in caged and on-floor houses the dust concentration during daytime or lighted period increased due to bird activity in comparison to nighttime/dark period (0.773 mg/m^3 IC95% [0.727-0.820] vs. 0.356 mg/m^3 IC95% [0.327-0.385]). The light led to a dramatic increase of dust in the air of all buildings, and in caged houses feed distribution also entailed a temporary increase of the dust burden.

Keywords: respirable dust, poultry house, laying hen, daily variation, husbandry practices

INTRODUCTION: The air in poultry houses is known to be contaminated by various potentially hazardous materials including gases (e.g. NH_3), chemicals such as disinfectants, and organic and inorganic dust. Organic dust in poultry houses consists of a complex combination of feed, litter, animal material such as feathers, skin, and fecal particles (Ellen et al., 2000). The housing system for laying hens greatly influences the airborne dust concentration with higher levels of dust in alternative systems than in cage systems (Le Bouquin et al., 2011). The influence of furnishing cages is less clear. Low levels of dust were observed in Norwegian buildings with furnished cages (Nimmermark, et al., 2009) but high dust concentrations were reported in French farms with large furnished cages (Huonnic et al., 2009). The degradation of air quality in alternative systems is due to providing hens with litter and to high bird activity. As a consequence of this atmospheric contamination, the high frequency of respiratory health problems among workers in poultry confinement buildings has often been reported (Radon et al., 2002; Rylander and Carvalheiro, 2006). Thus a French epidemiological study, called the AIRPOUL project, was performed to more precisely characterize air quality and worker exposure to aerial dust in houses for laying hens. This paper reports the results from the portion of the AIRPOUL project devoted to the air quality study and, more precisely, to the daily variations of dust concentration in the ambient air of henhouses. The objectives were to describe the evolution of respirable dust concentration over a 24-hour period and to identify rearing and ventilation management practices influencing this concentration.

Better understanding the evolution of ambient dust concentration during one day could contribute to identifying the most exposing periods for poultry workers and the activities that could entail discharges of aerial dust from the poultry house into the environment.

1. MATERIAL AND METHODS:

1.1. Farms studied: This field study occurred from March to November 2011 on a sample of 15 henhouses stratified according to housing system: 8 poultry houses where hens were kept in cages and 7 buildings where they were housed on-floor with access to an open-air run. The main characteristics of these farms are shown in (Table 1) Cage buildings were characterized by their large size and forced ventilation system, whereas the smaller poultry-houses in free-range systems were equipped with a natural ventilation system. The cages on 7 farms were furnished with a nest box and perches.

Table 1. Characteristics of caged and on-floor poultry houses. The median (range) is given for continuous variables.

	Cage	On-floor
Number of houses studied	8	7
Volume of the henhouse (m^3)	0.17 (0.13-0.21)	0.37 (0.32-0.46)
Housing capacity (hens/house)	40000 (19200-91200)	5000 (4495-6000)
Density (hens/m^2)	30.1 (23.9-44.7)	7.9 (7.1-9.4)
Access to an open-air run (number of houses)		
- Yes	-	7
- No	8	-
Ventilation (number of houses)		
- Natural	-	7
- Forced	8	-
Manure disposal system (number of houses)		
- Manure belts	8	-
- Dip pit	-	7
Number of hens per cage	42 (6-50)	-

1.2. Dust measurements: Concentration of respirable dust (diameter < 5 µm) in the ambient air of each poultry house was monitored over a 24-hour period with a laser photometer equipped with a cyclone captor (SIDEPAK® Aerosol Personal Monitor AM 510, TSI, Le Vaudreuil, France). The air sampler was placed 1.5 m above the ground in the middle corridor of the cage buildings and in the middle of the slatted area in the on-floor houses. The air flow was 1.7 l/min and was checked before sampling with a flowmeter (Primary Calibrator 4146, TSI, Le Vaudreuil, France). Hygrometry and temperature inside the poultry house was also recorded every 15 minutes with a data logger with specific sensors (KIMO KTHP 150B, KIMO Instruments, Rennes, France).

1.3. Data collection and analysis: Data on poultry buildings, ventilation regulation and husbandry conditions were collected in a questionnaire filled out with the farmer during an interview. On the day of dust monitoring, farmers reported their activities in the poultry house every 15 minutes in a space/time/activity questionnaire. The impact of building characteristics, husbandry practices, measurement conditions and farmer activities on dust concentration was assessed by calculating the Spearman coefficient

of correlation for continuous data and with the Kruskal-Wallis test on the ranks for qualitative parameters. For a given event happening during the day of measure (light starting, feed distribution, etc.), the average dust concentration calculated over the half hour after the event was compared with the concentration observed during the half hour before the event, using a Wilcoxon test for paired data.

2. RESULTS AND DISCUSSION:

2.1. Variations of dust concentrations over 24 hours: The concentration of respirable dust in the air emerged as higher and more variable in on-floor poultry houses than in caged buildings (Figure 1): 0.848 mg/m^3 (CI95% [0.774-0.894]) versus 0.429 mg/m^3 ([0.409-0.449]), P<0.01. This difference was previously reported in AIRPOUL and other studies in on-field conditions (Takai et al., 1998) and is now confirmed by monitoring over 24 hours. However, ambient dust concentration was lower in on-floor buildings than in caged buildings during the night because in half of the caged poultry houses, lighting programs included two light periods during the night to limit red mite infestation. Light enhances bird activity and consequently increases dust concentration in the air, as clearly demonstrated in broilers by Calvet et al. (2009). As an example, the average dust concentration was 0.471 mg/m^3 CI 95% [0.447-0.495] during the light period in caged poultry houses versus 0.353 mg/m^3 (IC 95% [0.321-0.385]) during the dark period (P<0.01). The difference was even higher in on-floor buildings where the average dust concentration increased from 0.346 mg/m^3 (CI95% [0.298-0.394]) during the night to 1.110 mg/m^3 (CI95% [1.040-1.118]) during the day. Both in caged and in on-floor poultry houses, average dust concentration in the air positively correlated to inside air temperature and negatively to relative humidity. This last correlation was expected, as water fogging is an effective method to lower dust generation from litter in on-floor henhouses (Gustafsson and von Wachenfelt, 2006).

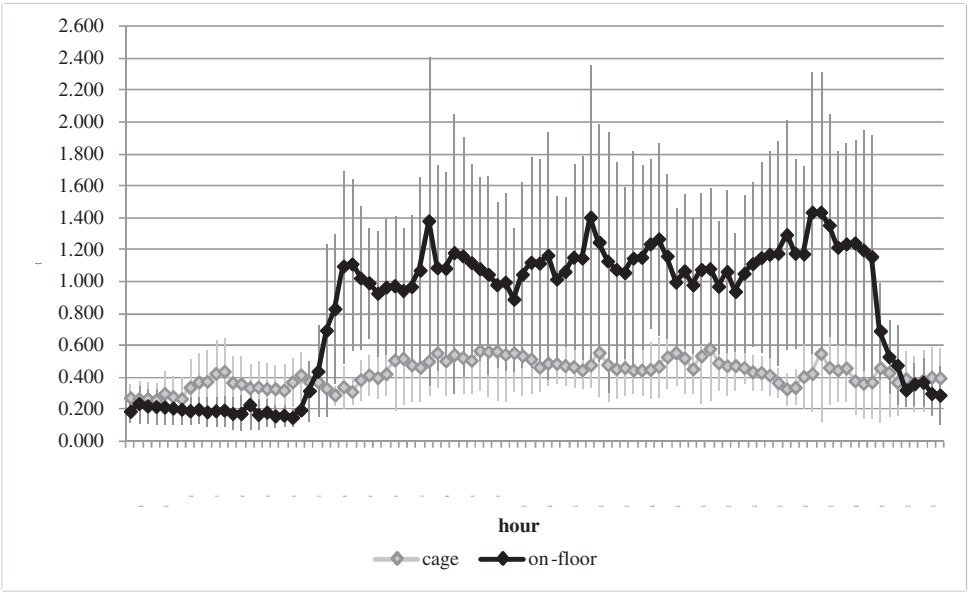

Figure 1. Variations over 24 hours of the average concentration of respirable dust in the air of caged and on-floor poultry houses. Vertical lines denote confident interval of the mean at 95%.

2.2. Events influencing dust concentrations: The light starting in the morning led to a dramatic increase of dust concentration in the air of caged poultry houses (+ 198%, on average, during the half hour following lighting, P<0.01) and in on-floor buildings (+332%, P<0.01). Conversely, dust concentration during the half hour following light extinction did not significantly decrease but slowly declined over 2 or 3 hours. Farmers spent 1 to 3 hours per day inside the house and the presence of humans did not increase the dust concentration in the air. However, in caged houses, collecting eggs blocked in cages and gathering dead hens entailed a higher dust burden (0.555 mg/m^3, CI 95% [0.485-0.633]) than visual checking of hens and equipment (0.417 mg/m^3, CI 95% [0.349-0.477], P=0.03). In addition, average dust concentration was one-third higher (+ 34% in average, P=0.01) after feed distribution whatever the type of feeding system. Feed distribution is regularly mentioned as a factor influencing dust concentration in poultry houses; however, this assumption was confirmed by dust measures only in one study on a single house (Guarino et al., 1999). Our study demonstrates this impact, but only in caged houses; dust concentration may be too highly variable from one building to another in on-floor henhouses to clearly identify common patterns in evolution of the dust burden among the 7 houses studied. Despite that very high levels of respiratory dust were reached during the day in on-floor houses, the observed dust concentration never exceeded the threshold fixed at 5 mg/m^3 for an 8-hour exposure by French legislation on occupational health (INRS, ED 924, 2008). However, this threshold is fixed for inert dust and Donham et al. (2000) demonstrated that pulmonary function decrements in poultry workers occur for an exposition to respiratory dust from poultry houses higher than 0.16 mg/m^3. The average dust concentration observed in 14 out of 15 henhouses exceed this threshold during daytime.

CONCLUSION: The present study confirmed that high levels of respirable dust occurred in the air of henhouses, especially in on-floor buildings rather than caged buildings, and during lighted periods in comparison with dark periods. Although the average concentration remained under the occupational threshold, the high levels of dust observed may generate concern for worker respiratory health. Use of individual respiratory protection should be recommended, especially for the most exposing working situations. The light starting entailed a peak in aerial dust concentration in all houses, and in caged houses feed distribution also led to a temporary increase of the dust burden.

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GREENHOUSE GAS AND AMMONIA EMISSIONS FROM BOVINE SLURRY STORAGE IN IRELAND

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ABSTRACT: Agricultural greenhouse gases (GHG) in Ireland are responsible for 18.6Mt of carbon dioxide (CO_2) equivalents (or 30.5% of national emissions). Methane (CH_4) comprises 60% of total agricultural emissions, with enteric fermentation and manure management responsible for 80% and 20% of these methane emissions, respectively. In addition, 98% of Ireland's ammonia (NH_3) emissions are attributable to agriculture, 82% of which arise from bovine systems. The objective of this laboratory-scale experiment was to quantify the effect of animal type, diet and temperature on greenhouse gas (methane) and ammonia emissions from bovine slurry during storage.
Manure was collected from bovine animals fed two diets. Two pairs of animals were used to collect the manure. Two animals were female bovines approximately 8 months old (Fe), and 2 were steers approximately 13 months old (St). Diet one was 100% grass silage (GS), diet two was ad lib concentrates and straw (CO). The slurry was frozen for the period between collection and incubation. The incubation was performed over two weeks in climate-controlled rooms at four different temperatures (5, 10, 15 and 20°C) and with 80% relative humidity. Gaseous emissions of methane CH_4, and NH_3 were measured on days 0, 5, 9, 14. Methane was measured using static chambers, with samples analysed on a Varian CP-3800 Gas Chromatograph (Agilent Ltd., Cork, Ireland). Ammonia was measured using a closed dynamic chamber coupled to an Innova 1412 Photoacoustic Field Gas Monitor (LumaSense Technologies, Inc., Denmark).
The results showed that the highest CH_4 and NH_3 emissions were associated with manure produced from the GS diet. The interaction of diet and animal type was also significant. Methane emissions increased with increasing temperature; however, this trend was not as apparent in the case of NH_3. The inclusion of diet and storage temperature as factors may increase the accuracy of emission inventory calculations. The results also indicate that these factors may help identify mitigation tools for reducing emissions. Further work is required to relate these emissions data to varying manure characteristics and farm-scale housing systems.

Keywords: GHG, ammonia, slurry, cattle, storage

INTRODUCTION: Animal production systems are significant contributors in terms of gaseous emissions from a range of specific and diffuse sources, including animal housing, grazing, manure storage and land-spreading. In Ireland, agriculture contributes 18.6 Mt CO_2 equivalents or 30.5% of total GHG emissions and 98% of national ammonia (NH_3) emissions (Duffy et al. 2012, Hyde et al. 2003). This emissions profile arises because of the dominance of cattle and sheep livestock production in Irish agricultural output. Bovines account for over 80% of both greenhouse and transboundary gaseous emissions, with manure management comprising 12% of GHG emissions and 30% of ammonia emissions from the sector. Whilst the proportion of emissions sourced from manure management may be low compared to those associated with enteric fermentation or fertiliser application, the mitigation potential could be high (Amon et al. 2006). The objective of this

laboratory-scale experiment was to quantify the effect of animal type, diet and temperature on CH_4 and NH_3 emissions from bovine slurry in storage.

1. MATERIAL AND METHODS: Manure was collected from four animals housed for a period of eight weeks on raised slatted floors. The animals were separated into two groups: 2 females approximately 8 months old (Fe), and 2 steers approximately 13 months old (St). Each pair of animals was separated from the other to avoid cross contamination of the manure. Manure was collected in trays placed under slatted concrete floors during the collection period. The animals were fed two diets (grass silage (GS) and 100 % *ad lib* concentrates and straw (CO)). Each diet was fed to the animals for a period of ten days prior to collection, to allow the digestive system to adapt to the diet. Manure was collected for seven days or until 200 litres of manure had been collected. The manure was then mixed and divided into batches of 25 litres and frozen until use in the incubation experiment. The duration of freezing varied between 10 and 18 weeks, dependant on the experimental run.

Slurries were incubated in 5 litre open cylinders, at 80 % relative humidity and at temperatures of 5, 10, 15, 20 $^{\circ}$C. The experiment was conducted as a randomised block design with four replications. Ammonia emissions were measured on days 0, 5, 9, and 14 of incubation, using a static chamber coupled to an Innova 1412 Photoacoustic Field Gas Monitor (LumaSense Technologies, Inc.). Fluxes were calculated based on concentration accumulation within the chamber over a five minute period. Methane emissions were also measured via syringe sampling over a 20 minute period, and analysed on a Varian CP-3800 Gas Chromatograph. Cumulative emissions of CH_4 and NH_3 were calculated as the sum of daily emission rates for the incubation period. Daily emission rates for days between sampling days were estimated by assuming a linear emission profile between sampling days. The effects of diet, animal type and temperature and their interactions on cumulative emissions over the 14-day period were analysed by Analysis of Variance using Proc Mixed in SAS.

2. RESULTS AND DISCUSSION: Methane emissions ranged from 0.17 mg m^{-2} d^{-1} to 91.5 mg m^{-2} d^{-1} with the GS diet and 0.16 mg m^{2} d^{-1} to 17.6 mg m^{-2} d^{-1} with the CO diet. Cumulative CH_4 emissions were significantly affected by animal type, diet and temperature ($P<0.0001$), with all two-way and three-way interactions also being significant ($P<0.0001$). The effect of diet and temperature on CH_4 emissions is shown in Figure 1. Emissions increased with an increase in temperature. These findings agree with those reported in Chadwick et al. (2011), who stated that CH_4 production is lower at temperatures below 15^{o}C, but increase exponentially above 15^{o}C. In terms of diet, only He-GS was significantly different ($P<0.0001$) at 15^{o}C and 20^{o}C compared to all other treatments.

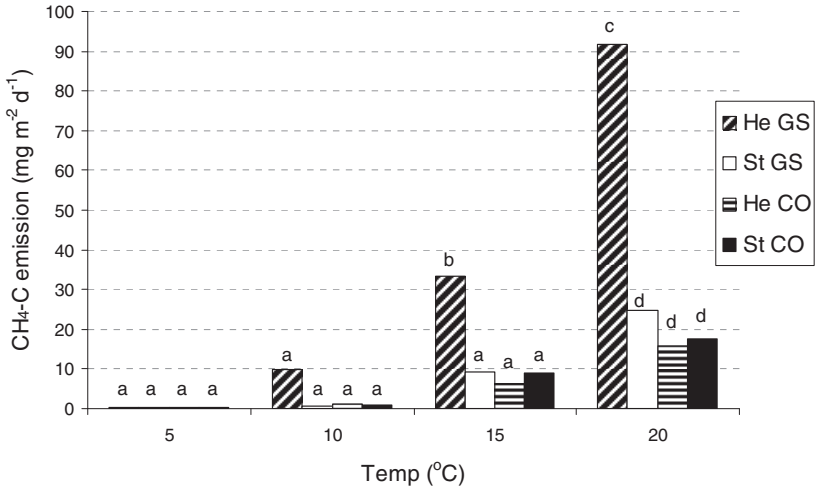

Figure 1. Temperature effect of diet on CH_4 emissions. (Letters indicate treatments where differences were significant at P<0.05).

NH_3 emissions range from 13.8 mg m^{-2} d^{-1} to 31 mg m^2 d^{-1} with the GS diet and from 6.1 mg m^{-2} d^{-1} to 9.9 mg m^{-2} d^{-1} with the CO diet (Figure 2). Cumulative NH_3 emissions were significantly affected by diet (P<0.0001) and temperature (P=0.020). All two-way interactions and three-way interactions of diet, animal and temperature were significant (P<0.05). Emissions are highest with the GS diet for both animal types when compared to the CO diet (P<0.0001). Emissions from the He slurry at 20°C was significantly different (P<0.0001) from the other treatments. The CO diet showed no significant differences between temperatures or between He and St.

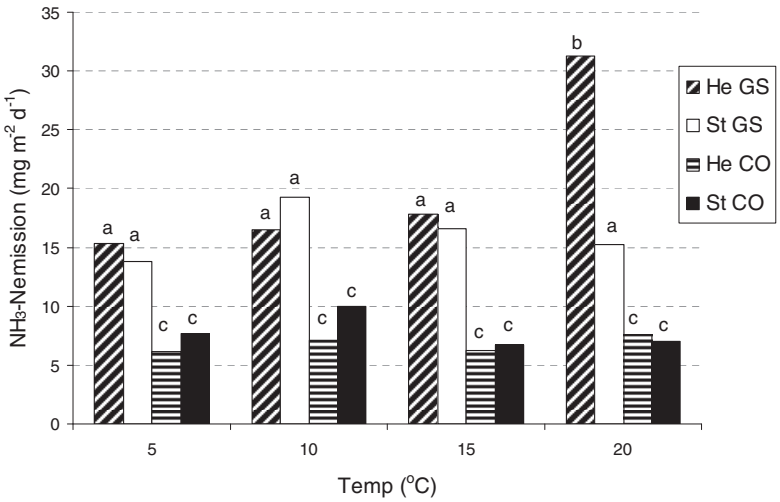

Figure 2. Temperature effect on NH_3 emissions. (Letters indicate treatments where differences were significant at P<0.05).

Methane and NH_3 emissions were highest with the He-GS treatment. However, the slurry from this treatment had the lowest dry matter (DM) content of 6 % with an increase in TAN content of 0.5 g kg^{-1} over the 14-day incubation period. By comparison, the average slurry DM content of the He-CO, St-GS and St-CO

treatments ranged from 10 % with a TAN decrease of 0.4g kg^{-1} over the 14-day incubation period. The lower DM content of heifer diet 1 could have inhibited the formation of a crust. Therefore, NH_3 and CH_4 emissions would have been higher than that of diet 2 and that of the steers, as a crust formed on these treatments.

CONCLUSION: The results of this study show a positive correlation between CH_4 emissions and the temperature of the slurry during storage. The animal type also had a significant effect on emissions of CH_4 and NH_3, but the extent of this effect was dependant on the diet. Animal type, temperature and diet are important variables to be considered in developing or improving National Inventory data for both CH_4 and NH_3 emissions from bovine manure. Further work is required to relate these emissions data to varying manure characteristics and farm-scale housing systems.

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EMISSIONS OF GREENHOUSE GASES (METHANE AND NITROUS OXIDE) DURING STORAGE OF DIGESTED AND NON-DIGESTED SLURRY

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ABSTRACT: Digestion of slurry for biogas production can reduce net greenhouse gas (GHG) emissions from agriculture. This study quantified GHG emissions from non-digested and digested cattle slurry during storage in summer and winter and examined the effects of covering stored digested slurry. Emissions of methane (CH_4) and nitrous oxide (N_2O) were measured in a pilot-scale storage plant comparing non-digested and digested cattle slurry, with and without cover, during winter and summer. A closed chamber technique was used for gas sampling every second week. Daily mean CH_4 emissions during summer were 2.23, 6.94 and 6.58 g CH_4-C/m^3.d for non-digested, digested uncovered and digested covered slurry, respectively. During winter the corresponding emissions were 0.14, 0.01 and 0 g CH_4-C/m^3.d In the summer experiment, N_2O emissions were only detected from covered storage and corresponded to a daily mean of 0.07 g N_2O-N/m^2.d In general, during warm periods digested cattle slurry generated higher CH_4 emissions than non-digested. During cold periods CH_4 emissions were rather low, with the highest emissions from non-digested slurry. Covering stored digested slurry with a roof may create conditions promoting N_2O emissions during warm periods, but did not influence CH_4 emissions.

Keywords: Greenhouse gases, cattle slurry, digested, non-digested, storage

INTRODUCTION: Digestion of slurry for biogas production can benefit agriculture as it reduces net emissions of greenhouse gases (GHG) by recycling the methane (CH_4) from animal slurry, and this CH_4 can replace fossil fuel. This project examined ways to ensure climate-friendly handling of digested cattle slurry during storage. Specific aims were to quantify GHG emissions from non-digested and digested cattle slurry during storage in summer and winter and to determine the effects of covering stored digested slurry.

1. MATERIALS AND METHODS: GHG emissions from stored non-digested and digested cattle slurry were measured in summer (May 27 - August 25, 2010) and winter (December 16, 2010 - March 30, 2011).

1.1. Experimental site and design: The pilot-scale facility used in the storage experiment was situated outdoors, 4 km south of Uppsala (59°82´N, 17°65´E). It comprised nine containers half-buried in the ground, allowing GHG emissions to be measured from slurry stored under conditions similar to full-scale storage (Rodhe, Ascue, Nordberg, 2009). Each container was 1.5 m high, 1.63 m in diameter and had a basal area of 2.0 m^2. Three treatments were studied: (1) Non-digested cattle slurry without cover, (2) digested cattle slurry without cover, and (3) digested cattle slurry with cover. The experiment was organised as a randomised complete block design with three blocks and was run during two periods, during 88 days in summer and 105 days in winter. Differences between cumulative emissions values were analysed using

one-way ANOVA with blocks, followed by pair-wise comparisons with a t-test using PROC GLM in SAS.

1.2. Pig slurry and storage management: The non-digested and digested slurry were collected from a dairy farm with a digester plant. Fresh slurry was taken from a collection pit just filled with slurry from dairy cows and followers, and digestate was taken from a storage tank just after filling from the digester. The slurry was transported to the pilot storage plant and, before being placed in storage, well-mixed slurry/digestate was sampled and analysed for dry matter (DM), total nitrogen (Tot-N), total carbon (Tot-C), pH and volatile solids (VS) and total ammonia nitrogen (TAN). Maximum methane production (B_0) was also analysed for three samples of slurry and digestate, taken in each season, using a laboratory-scale batch digester run for 100 days at a constant temperature of 37°C (Rodhe et al., 2009). The storage containers were then filled with approx. 1 m of slurry/digestate. Temperature in the slurry was recorded hourly with thermocouples at 0.1 m from the bottom and 0.1 m from the surface (Intab Interface-Teknik AB, Stenkullen, Sweden).

1.2. Gas measurements: Gaseous emissions from the storage containers were measured using a closed chamber technique by inserting a gastight cover 0.2 m above the slurry surface (Rodhe et al., 2009). The first sampling was conducted one day after filling when the slurry had settled, and then approximately every second week. Before sampling, a first headspace sample was withdrawn directly after closing the cover and the next two samples 15 and 30 minutes later. The gas samples were analysed for CH_4 and nitrous oxide (N_2O) by gas chromatograph (HP 6890, Hewlett Packard, Palo Alto, CA, USA). The fluxes were calculated by linear regression from the concentration changes over time.

2. RESULTS AND DISCUSSION:

2.1. Storage conditions: Slurry properties prior to storage are presented in Table 1. The properties of non-digested slurry differed between storage periods depending on farm conditions prevailing at collection, e.g. relative proportions of slurry from dairy and follower cows, house cleaning, production level, climate etc. The properties of the digestate at filling varied less between storage periods due to a hydraulic retention time of 20 days in the digester. The B_0 value for non-digested slurry pre-storage was approximately twice that of digested slurry (Table 1). Mean temperature of the stored non-digested slurry was 14.2°C and 2.1°C in summer and winter, respectively. The stored digested slurry had about 0.2°C higher mean temperature in both seasons.

2.2. Gas emissions: Daily mean CH_4 emissions during summer were 2.23, 6.94 and 6.58 g CH_4-C/m^3.d for non-digested, digested uncovered and digested covered slurry, respectively. There was a trend of declining emissions during the summer experimental period (Figure 1). During winter the corresponding mean emissions were 0.14, 0.01 and 0 g CH_4-C/m^3.d (Figure 2). These emissions began about three weeks after the start of the storage experiment and continued until the end (Figure 3).

Table 1. Properties of non-digested and digested slurry at the beginning of the summer and winter storage experiments.

	Non-digested slurry		Digested slurry	
Content	Summer	Winter	Summer	Winter
DM, %	7.9	3.3	5.0	4.1
VS, % of DM	84	76	76	72
pH	7.2	7.4	7.7	7.9
Tot-N, kg/ton	3.2	1.9	2.8	3.0
NH_4-N, kg/ton	1.25	1.0	1.50	1.9
Tot-C, kg/ton	35.6	15	20.7	17
B_0, normal-ml CH_4 g^{-1} VS	270	239	121	121

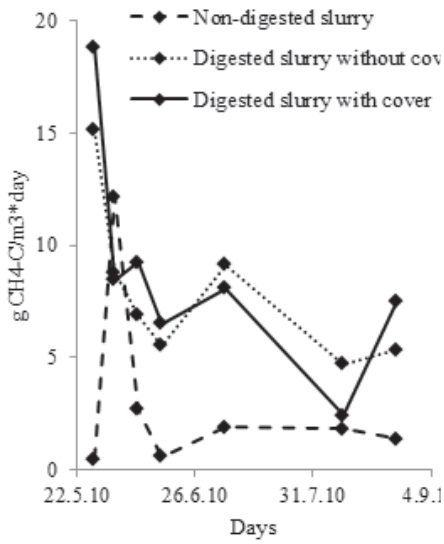

Figure 1. Daily mean methane emissions (g CH_4-C/m^3.d) over time during summer.

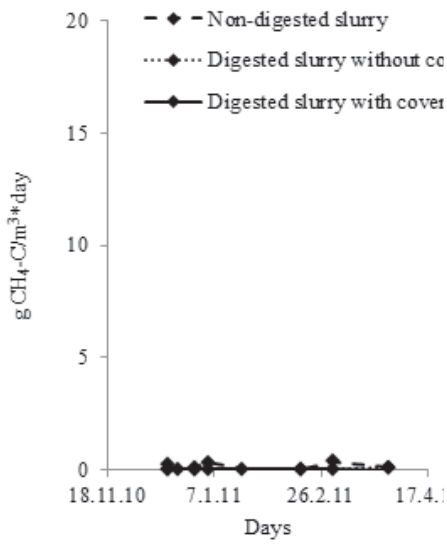

Figure 2. Daily mean methane emissions (g CH_4-C/m^3.d) over time during winter.

Emissions of N_2O were only detected from the covered storage in summer, where they corresponded to a daily mean of 0.07 g N_2O -N/m^2.d. During winter only very low N_2O emissions (<0.01 g N_2O -N/m^2.d) were detected. Table 2 shows cumulative emissions of CH_4 and N_2O for both storage periods. In winter, there was no significant difference in cumulative emissions of either CH_4 or N_2O between treatments.

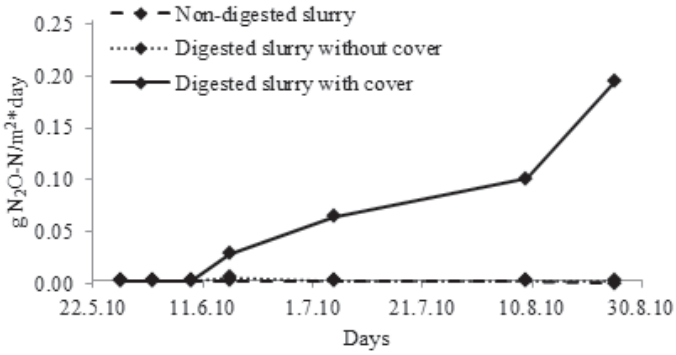

Figure 3. Daily mean nitrous oxide emissions (g N_2O-N/m^2.d) over time during summer, treatment means.

In summer, cumulative CH_4 emissions from non-digested slurry were significantly lower than those from digested slurry, while covering the digested slurry during storage had no significant effect on CH_4 emissions in summer or winter. However, covering the digested slurry gave significantly higher N_2O emissions in summer compared with leaving it uncovered. In winter no significant differences were found between the storage types.

Table 2. Mean cumulative emissions of CH_4 (g CH_4-C/m^3) and N_2O (g N_2O-N/m^2) during storage of non-digested and digested slurry, without and with cover, in winter and summer.

	Summer		Winter	
Slurry	CH_4	N_2O	CH_4	N_2O
Non-digested slurry	196.01[a]	-0.02[a]	14.67[a]	0.00[a]
Digested slurry without cover	610.93[b]	0.03[a]	1.25[a]	-0.01[a]
Digested slurry with cover	578.72[b]	6.04[b]	-0.14[a]	0.01[a]

[a,b] Means with different letters within each column are significantly different ($p<0.05$).

CONCLUSIONS: In general, during warm periods digested cattle slurry generated higher CH_4 emissions than non-digested slurry, despite having a lower B_0 value. During cold periods CH_4 emissions were rather low, with the highest emissions from non-digested slurry. Covering stored digested slurry with a roof may create conditions promoting N_2O emissions during warm periods, but did not influence CH_4 emissions.

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THE EFFECT OF CONCENTRATE STARCH CONTENT ON ENTERIC METHANE EMISSIONS OF LACTTAING DAIRY COWS

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ABSTRACT: Six multiparous Holstein dairy cattle (live weight = 568±42.9 kg and lactation days = 32±7.3) were used in a 3-period (4 weeks/period) changeover study to evaluate effects of two concentrate supplements (high starch vs. high fibre) on animal production and enteric methane (CH_4) emissions. The high starch and high fibre concentrates had a similar content of CP (210 g/kg DM) and GE (18.5 MJ/kg DM), but different contents (g/kg DM) of starch (414 vs. 76), ADF (85 vs. 210) and NDF (216 vs. 348). The animals were offered 10 kg/day (fresh weight) of concentrates and allowed ad libitum intake of grass silages, and were housed in cubicle accommodation for 18 days before a 10-day measurement period in metabolism units, with enteric CH_4 emissions determined over the final 3 days using indirect open-circuit respiration calorimeter chambers. Concentrate type (starch vs. fibre) had no significant effect on silage DM intake, total DM intake, ME intake, live weight or milk yield. Cows offered the high starch concentrate had a lower CH_4 emission rate, expressed either as total emission (325 vs. 356 g/day), or as a proportion of milk yield, DM intake (19.4 vs. 20.4 g/kg), OM intake, GE intake (0.058 vs. 0.062 MJ/MJ), DE intake or ME intake, but none of the differences reached significance. The present study indicated that concentrate starch levels had no significant effect on enteric CH_4 emissions of lactating dairy cows.

Keywords: dairy cows, fibre content, methane emission, starch content

INTRODUCTION: Methane (CH_4) is a greenhouse gas that remains in the atmosphere for approximately 9 to 15 years. Methane is over 20 times more effective in trapping heat in the atmosphere than CO_2 over a 100-year period and is emitted from a variety of natural and human-influenced sources (United States Environmental Protection Agency, 2007). Livestock farming is a major contributor to atmospheric CH_4 accumulation. The enteric fermentation of ruminants accounts for a major part of total CH_4 emissions from livestock farming, especially in Europe, North America, Australia, and New Zealand, where beef, lamb, and milk are major food sources for humans. Globally, the livestock sector produces 37% of all human-induced CH_4 (Steinfeld et al., 2006). At present, there is increasing pressure to reduce greenhouse gases (GHG) from all sectors of the economy. Recent European Union legislation requests that member nations reduce total GHG from 1990 levels by 20% by 2020 (European Union, 2008), and the UK Climate Change Act (UK Office of Public Sector Information, 2008) sets a target of 80% reduction from 1990 levels by 2050. The implementation of these targets will have major implications for ruminant livestock systems. Consequently, there is increasing interest in research to reduce enteric CH_4 emissions from ruminant animals.

Methane emission from enteric fermentation of cattle is influenced by a range of dietary and animal factors, e.g., forage proportion in the diet (Yan et al. 2010). However, there is little information available on the effect on enteric CH_4 emissions from high yielding cows at early lactation offered diets containing different starch contents. Therefore, the objective of the present study was to evaluate the possibility of whether the manipulation of concentrate starch levels could reduce enteric CH_4 emissions from early lactating dairy cows.

1. MATERIAL AND METHODS: Six multiparous Holstein dairy cattle were used in a changeover study for 3 periods (4 weeks/period) to evaluate effects of two concentrate supplements (high starch vs. high fibre) on animal production and enteric CH_4 emissions. At the commencement of the study the animals were 32 (s.d., 7.3) days post partum and had a live weight of 568 (s.d., 42.9) kg. The animals were offered 10 kg/day (fresh weight) of concentrates and allowed ad libitum intake of grass silages. The grass silages were produced from perennial ryegrass swards. The concentrate ingredient composition and chemical analysis of concentrates and silage are presented in Table 1.

Table 1. Concentrate ingredient composition and feed nutrient concentration.

		High starch concentrate	High fibre concentrate	Silage
Concentrate ingredient composition (g/kg, fresh basis)				
	Soyabean meal	136	136	
	Cottonseed	50	170	
	Rapeseed	38	38	
	Fish meal	13	13	
	Molasses	30	30	
	Water	20	20	
	Barley	293	0	
	Wheat	293	0	
	Maize Gluten	127	0	
	Sugar beet pulp	0	443	
	Citrus pulp	0	150	
	Total	1000	1000	
Nutrient concentration (DM basis)				
	DM (g/kg)	866	882	201
	Ash (g/kg DM)	49	67	86
	Total N (g/kg DM)	34	33	23
	Gross energy (MJ/kg DM)	18.7	18.3	18.1
	ADF (g/kg DM)	85	210	394
	NDF (g/kg DM)	216	348	
	Starch (g/kg DM)	414	76	
	pH			4.1
	Ammonia-N/total N			0.10

During each period, the animals were housed in cubicle accommodation for 18 days and then in metabolism units for 10 days. In the metabolism units, feed intake was recorded, faeces and urine collected, and enteric CH_4 emissions determined over the final 3 days using indirect open-circuit respiration calorimeter chambers (Yan et al., 2010).

Milk yields were recorded daily throughout the study. Milk samples were taken during the final 10 days of each period for analysis of milk composition. Samples of feed ingredients, faeces and urine were taken daily during the digestibility trials and chamber measurements of each period. The methods adopted for chemical analysis of these samples were as described by Mayne and Gordon (1994).The results were statistically analysed using one-way ANOVA with experimental period as block. The

statistical program used in the present study was Genstat 10.1 (tenth edition, Lawes Agricultural Trust, Rothamsted, UK).

2. RESULTS AND DISCUSSION: The results on animal performance and enteric CH_4 emissions are presented in Table 2.

Table 2. Effects of concentrate starch content on animal performance and enteric methane emissions oflactating dairy cows.

	High starch concentrate	High fibre concentrate	s.e.	P values
Silage DM intake (kg/day)	8.1	8.7	0.63	0.519
Total DM intake (kg/day)	16.7	17.5	0.63	0.440
ME intake (MJ/day)	197	199	7.3	0.914
Live weight (kg)	561	575	15.5	0.529
Milk yield (kg/day)	21.6	23.4	1.16	0.301
CH4 emission (g/day)	325	356	20.1	0.294
CH_4/DM intake (g/kg)	19.4	20.4	0.90	0.431
CH_4/OM intake (g/kg)	21.0	22.0	0.99	0.514
CH_4/Milk yield (g/kg)	15.2	15.5	1.00	0.822
CH_4-E/GE intake (MJ/MJ)	0.058	0.062	0.0028	0.309
CH_4-E/DE intake (MJ/MJ)	0.079	0.085	0.0035	0.198
CH_4-E/ME intake (MJ/MJ)	0.091	0.099	0.0044	0.187

Concentrate type (starch vs. fibre) had no significant effect on silage DM intake or total DM intake, thus resulting in a similar dietary silage proportion between the 2 diets (484 vs. 497 g/kg DM). The diet type also had no significant effect on ME intake, live weight or milk yield. Cows offered the high starch concentrate diet had a lower CH_4 emission rate, expressed either as total emission (g/day), or as a proportion of milk yield, DM intake, OM intake, GE intake, DE intake or ME intake, but none of the differences reached statistical significance. The ratios of CH_4 energy/GE intake obtained in the present study are marginally lower than that (0.065) recommended by the Intergovernmental Panel on Climate Change (IPCC, 2006) for use to develop CH_4 emission inventories from enteric fermentation for cattle where no CH_4 emission data are available. However, the average value (0.060) from the 2 diets in the present study is in the mid range of CH_4 energy/GE intake, as reported by Moe and Tyrrell (1979) in a meta-analysis of a large dataset (n = 404 trials) with Holstein cows in the United States (0.016 to 0.099), and by Yan et al. (2000) with 247 Holstein-Friesian cows in United Kingdom (0.037 to 0.101).

CONCLUSION: The present study indicates that concentrate starch levels had no significant effects on enteric CH_4 emissions from lactating dairy cows.

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NITROUS OXIDE EMISSION FACTORS FOR SHEEP URINE DEPOSITED ON HILL COUNTRY

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ABSTRACT: New Zealand grazed hill country represents a large source of nitrous oxide (N_2O) emissions, where spatial differences in soil conditions across hill land units (HLUs; slope, aspect and soil type) are highly variable. Also, excretal-N deposition regulated by animal grazing and resting behaviour may impact emission factors (EF_3).We hypothesise that EF_3 is lower on medium and steep slopes compared to low slopes, and that we can use this knowledge of spatially different EF_3 values to provide a better inventory of N_2O emissions from New Zealand hill country. We report on N_2O emission factors for sheep urine determined in four regions in New Zealand (Waikato, Manawatu, Southern Hawkes Bay and Otago). Urine was applied to low (< 12°) and medium (12° - 25°) slopes in spring 2009 and again in autumn 2011 in each region. N_2O emissions were measured for 3-4 months using static chambers.

Large variations in EF_3 existed within each region, between regions and at each slope class. Over all regions, there was a marginally significant (P = 0.08) difference in EF_3 for sheep urine spring-applied to medium and low slopes, averaging 0.08% and 0.46%, respectively. In the autumn trial there was no slope effect, with EF_3 averaging 0.11% and 0.12% on medium and low slopes, respectively. By combining the datasets, there was a marginally significant (P = 0.06) difference in EF_3 for low slopes and medium slopes (0.26 and 0.10%, respectively). Variation between regions may be partly explained by soil fertility status in spring trials and soil moisture content in autumn trials.

National N_2O emissions from sheep-grazed hill country were estimated using a spatial framework model that disaggregates excreta deposition according to slope class. Using EF_3values of 0.26% and 0.10% for low and medium slopes, respectively, with EF_3 for steep slopes (> 25°) assumed to be the same as that for medium slopes, the estimated loss was 2.2 Gg N_2O/y, which is 81% lower than 11.5 Gg N_2O/y, based on the country-specific EF_3 value of 1%.

Keywords: N_2O, emission factor, inventory, sheep urine, hill country, slope

INTRODUCTION: New Zealand (NZ) has a unique greenhouse gas (GHG) emission profile, with agriculture accounting for almost half of the national total (Ministry for the Environment, 2011). Of this, nitrous oxide (N_2O) emissions account for approximately one-third, with direct N_2O emissions from excreta deposited directly onto soils being the main contributor. NZ has a country-specific emission factor for direct deposition of urine onto soil (EF_3) of 1%, which is largely based on N_2O emission measurements from cattle urine applied to intensively-managed lowland dairy pastures. However, nearly one half of the national livestock population, mainly sheep and beef cattle, graze in hill country pastures where soil microbial activity and soil fertility is generally lower. In these environments, slope influences grazing and excretal deposition, with disproportionately more sheep excreta deposited on low slopes (58%) due to stock resting behaviour (campsites), compared to 30% and 12% for medium and steep slopes, respectively (Saggar et al., 1990). As a result,

the EF_3value for low slopes is likely to be higher than on medium slopes due to higher soil fertility and microbial activity. The objective of this study was to determine N_2O EF_3values for urine applied to low (< 12°) and medium (12° - 25°) slopes in four regions in NZ (Waikato, Manawatu, Southern Hawkes Bay and Otago). The EF_3 values were used for determining N_2O emissions from hill country using a spatial framework that distributes animal excreta according to slope class (de Klein et al., 2009). Total N_2O emissions were compared to those based on EF_3 = 1%.

1. MATERIAL AND METHODS:

1.1. Approach: Field trials were conducted in spring (November) 2009, and repeated on nearby sites in autumn (May) 2011 to determine cumulative N_2O emissions from sheep urine applied to low and medium slopes of hill land on free-draining soils in 3 regions and on a poorly draining soil in 1 region of NZ. All stocks were excluded from sites for at least one month before commencement of each experiment. Following collection of sheep urine from ewes grazing hill country pastures typical for each region, 150 mL was applied to the low slope soil within a 22 cm diameter plot to represent typical sheep urination volumes (equivalent to 4 L/m^2). Consequently, rates of N applied varied between 224-464 kg N/ha and 236-325 kg N/ha in spring and autumn, respectively. On medium sloped areas the volume was reduced by 33% to account for urine runoff, estimated from visually assessing runoff using dyed water. Non-excreta control treatments were included, with treatments applied in a randomised block design (n=5). Adjacent to each gas sampling plot was a similarly treated soil sampling plot (0.5 × 1.0 m). Gas and soil sampling was conducted regularly until N_2O emissions reached background levels (*ca*4 months).

1.2. Soil and climatic parameters: At the start of each trial, soil bulk density and Olsen P levels were determined to 75 mm depth in low and medium slopes at each site. Soil sampling plots were treated similarly to gas plots, and samples collected for determining soil moisture. Samples were thoroughly mixed and then dried at 105ºC for 24 hours, to determine soil water metrics (volumetric water content and water-filled pore space (WFPS). Hourly rainfall, ambient air and soil temperatures (at 5 cm depth) were logged for the entire trial period at a meteorological site as close as possible to the trial site.

1.3. Nitrous oxide and emission factor determination: N_2O emissions were measured using a standardised static chamber technique where fluxes (mg N/m^2/h) were calculated from the increase in headspace N_2O over a 45 to 60 min period (de Klein et al., 2003). The emission factors were then calculated for each block (equation 1).

$$EF_3 = \frac{Urine\ N_2O - Control\ N_2O}{Urine\ N\ applied} \times 100 \quad (1)$$

where EF_3 is emission factor (N_2O-N emitted as % of urine-N applied), Urine N_2O and Control N_2O are the cumulative N_2O emissions from urine and control plots, respectively (kg N/ha), with Urine N applied as kg N/ha. The EF_3 data underwent a log (x+a) transformation prior to analysis using Genstat (vers. 13), where a= 0.3, 0.1 and 0.25 in the spring, autumn and combined datasets, respectively. Following back-transformation, EF_3 values for low and medium slopes from the combined dataset were used within the spatial framework, which allocates slope classes across hill country regions, to estimate national N_2O emissions for sheep-grazed hill country based on stock numbers for 2007. We assumed EF_3 for steep slopes was the same as medium slopes.

2. RESULTS AND DISCUSSION: N_2O emissions increased following urine application, returning to background levels within 5-7 weeks. In the spring experiment, across all regions, cumulative N_2O emissions from urine averaged 1.84 kg N/ha (SEM = 0.99), whereas those from control plots were 0.30kg N/ha (SEM = 0.16).In the autumn trial, average cumulative N_2O emissions from the urine plots were 0.67 kg N/ha (SEM = 0.13) compared to 0.30 kg N/ha (SEM = 0.10) for control plots.

Table 1. EF_3 values for sheep urine applied to low and medium slopes in four regions of New Zealand for two seasons.

Region	Drainage class	Slope	Spring 2009 EF_3	Autumn 2011 EF_3	Combined EF_3
Waikato	Free	low	0.52	0.12	
		medium	0.05	0.25	
Manawatu	Free	low	1.53	0.06	
		medium	0.21	0.03	
Southern Hawkes Bay	Poor	low	0.06	0.12	
		medium	0.00	0.02	
Otago	Free	low	0.36	0.22	
		medium	0.05	0.21	
Mean		low	0.47	0.12	0.26
		medium	0.08	0.11	0.10
P-value [A]			*0.08 (*)*	*0.73 (NS)*	*0.06 (*)*

[A] *=significant at 10% level; NS = not significant

Both trials showed large variations in EF_3, both within a region and between regions, at each slope class. Over all regions, the spring EF_3 for urine on low slopes was higher than that applied to medium slopes (Table 1: 0.47% and 0.08%, respectively), although the difference was only marginally significant ($P = 0.08$). In autumn, EF_3 for urine on low and medium slopes was similar (0.12% and 0.11%, respectively). Combining the datasets produced a higher EF_3 value for low slopes (0.26 and 0.10%, respectively), although this difference was only marginally significant ($P = 0.06$).

Variation between regions and seasons can be partly explained by soil fertility status and soil moisture content. The spring EF_3 values showed a positive relationship with soil phosphorus (Olsen P) levels (data not shown; $R^2 = 0.56$, $P = 0.03$, n=8). Soil P itself does not affect N_2O emissions, but in sheep-grazed campsites the nitrogen, carbon and P cycles are closely linked through the higher return of animal excreta at these sites. The observed relationship between Olsen P and N_2O emissions may be due to lower nitrification rates in lower fertility medium slopes compared to higher fertility low slopes (Letica et al., 2006).While there was no significant relationship between EF_3 and Olsen P during the autumn trial, possibly partly due to the smaller range in Olsen P values, combining data from both trials resulted in a stronger significant relationship than for the spring results alone ($R^2 = 0.51$, $P = 0.002$, n=16). The autumn EF_3 tended to increase with increasing average WFPS measured over the first 6 weeks (data not shown; $R^2 = 0.46$, $P = 0.06$, n=8), where WFPS ranged from 58 to 91%. A similar relationship was observed for dairy urine on lowland pasture, noting that anaerobicity increases with WFPS, stimulating N_2O production via denitrification (van der Weerden et al., 2011). There was no relationship between spring EF_3 and WFPS, possibly because the WFPS values were at or above field capacity (71-90%) and thus not limiting N_2O emissions.

The combined EF_3value for low and medium slopes across both trials was 0.26 and 0.10%, respectively. Assuming EF_3 for steep slopes is similar to medium slopes,

national N_2O emissions from sheep-grazed hill country based on a spatial framework model that disaggregates animal excreta distribution and EF_3 values across slope classes (de Klein et al., 2009) were estimated at 2.2 Gg N_2O/year. This estimation incorporates the effect of sheep grazing and resting/camping behaviour in hill country while utilising EF_3 values determined under such conditions. Therefore, we consider this approach to be an improvement over the current inventory approach, where N_2O emissions are estimated to be 11.5 Gg N_2O/year based on New Zealand's country-specific EF_3 value of 1%.

CONCLUSION: Field trials in hill country demonstrated that the mean EF_3 for sheep urine was 0.26 and 0.10% of the N applied for low and medium slopes, respectively. This is considerably less than the current country-specific value of 1%. Using a spatial framework model and EF_3 values from the field trials, national N_2O emission from sheep-grazed hill country was estimated at 2.2 Gg N_2O/year.

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Part III.
Mitigation strategies

FARMING FOR A BETTER CLIMATE BY IMPROVING NITROGEN USE EFFICIENCY AND REDUCING GREENHOUSE GAS EMISSIONS (FARMCLIM)

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ABSTRACT: FarmClim is a project that assesses N and GHG fluxes in Austrian agriculture and proposes measures for improvement. These measures will undergo an economic assessment. The IPCC default emission factor for soil N_2O emissions will be reviewed and improved, including the development of regional concepts to implement mitigation measures. Reporting to international bodies (UNFCCC and European Union) will be improved to adequately reflect emission mitigation efforts, and uncertainties will be reduced. FarmClim covers the topic in a multi- and interdisciplinary approach including experts from science, reporting and commercial farming. The inclusion of stakeholders` views at an early project state will contribute significantly to closing the science-policy gap in the field of climate-friendly farming. While the project extends to Austria only, the concepts are meant to be general and will be disseminated to different European bodies. The FarmClim consortium comprises the University of Natural Resources and Life Sciences, Vienna, the Austrian Agency for Health and Food Safety, the Austrian Umweltbundesamt GmbH, the Chamber of Agriculture of Lower Austria and the Karl Franzens University, Graz.

Keywords: climate and food; nitrogen use efficiency; science-policy-gap; sustainable animal and crop production; greenhouse gas modelling and mitigation

INTRODUCTION: Nitrogen positively contributes to food and energy security, increasing yields in constant global agricultural land use. Human activity has doubled the level of reactive nitrogen (Nr) in circulation, largely as a result of mineral fertilizer production and fossil-fuel burning. A better understanding of the interactions of human-induced formation of reactive N and natural and managed ecosystems is an essential component in achieving sustainability.

There is much interest in understanding effects of agricultural activities on greenhouse gas emissions. Management practice has the scope to influence the magnitude of gaseous losses, and the potential to reduce GHG emissions. It is essential to understand ways agricultural activities influence nitrous oxide (N_2O) and methane (CH_4) emissions. Considerations must comprise emissions from all stages of the manure management continuum, including animal housing, yards, manure storage and treatment, and land spreading.

The general objectives of FarmClim are: Optimise N use in Austrian Agriculture; Minimise N and GHG losses to the environment; Identify intervention points in agriculture which are relevant for a general N and GHG strategy; Develop a basis on which guidelines on recommendations for agricultural advisory services on potential optimisation measures and their economic impact can be developed; Close the science-policy gap on the possibilities to optimise N use and minimise GHG losses.

1. MATERIAL AND METHODS: Agricultural activities contribute to emissions of nitrogen and greenhouse gases through a variety of processes. Sources and sinks of the direct greenhouse gases (GHG) carbon dioxide (CO_2), CH_4, N_2O, HFC, PFC, and SF_6, and of the indirect GHGs, NO_x, NMVOC, CO, and SO_2 are reported under the United Nations Framework Convention on Climate Change (UNFCCC). The Conference of the Parties (COP) decided that a National Inventory Report (NIR) must be prepared annually. The NIR must provide transparent, consistent, comparable, complete, and accurate data on sources and sinks of national emissions and must evaluate the progress towards meeting the GHG reduction commitments under the Kyoto Protocol.

Inventory compliers rely on key concepts to ensure that inventories are comparable between countries, avoid gaps or double counting, and that the time series reflect actual changes in emissions. These key concepts are: transparency, accuracy, comparability, completeness, and consistency. To promote the development of high quality inventories, a collection of methodological principals, actions and procedures were defined and collectively referred to as good practice. Inventories consistent with good practice are those that contain neither over- nor under- estimates so far as can be judged, and in which uncertainties are reduced as far as practicable. When improving the inventory quality, the main focus lies in reducing uncertainties in estimation emissions from key categories. IPCC-GPG requires uncertainty estimates as an essential part of a complete emission inventory.

FarmClim will compile current estimates on N and GHG fluxes from Austrian agriculture. Current estimates will be evaluated and a list of possibilities for future refinement of flux estimation and will be developed. From this, FarmClim will produce a list of potential mitigation measures. Assessing nitrogen fluxes also provides an initial step to an overall nitrogen budget, a key element in studying intervention points to curb potentially damaging nitrogen fluxes in the environment (Sutton et al., 2011).

In crop production, an optimisation potential remains with respect to N fertilization and nutrient uptake efficiency. Based on existing literature (e.g. European Nitrogen Assessment) and current field experiments, the actual possibilities for minimising nutrient losses along the nitrogen cycle will be assessed in an IACS analysis (WP 3). These findings will serve as a basis for measure proposals to be addressed with advisors and farmers.

A soil modelling effort (WP4) will deepen the understanding of Austrian N_2O fluxes. Currently, N_2O emissions are estimated with the IPCC default emission factor, which uniformly applies to any Nr added to agricultural soil. This methodology does not allow differentiation of N_2O emissions due to regions and management practices. Mitigation measures become “valid” only when they can be reported appropriately, such that a differentiation actually is needed for improved management practices to be considered under the UNFCCC commitments.

In the proposed project, we plan to integrate available data from representative Austrian regions into the mechanistic and process-oriented model DNDC (Li et al., 1992), which is designed to predict greenhouse gas emissions from soils (Stange et al. 2000). Impacts of climate change (temperature, precipitation) and/or enhanced/reduced N-deposition will be modelled and compared to the currently used IPCC default value for N_2O-estimation (1% of N input). Subsequently, the DNDC model can be used within the scope of climate change scenarios as well as

modifications in management and fertilization plans. This opens a way to develop greenhouse gas mitigation strategies.

DNDC results will be used to develop scenarios of N fluxes under conditions of climate change, taking advantage of the downscaled climate model results of the reclip: century project (Loibl et al., 2011). Additionally, they will be compared to the results of the Austrian greenhouse gas inventory which has been established following IPCC 1997 methodology. Such a comparison will also allow better establishment of the contribution of N_2O emissions to the inventory uncertainty, notoriously seen as the most significant contributor to overall uncertainty (Winiwarter and Muik, 2010).

Economic efficiency of measures is a crucial factor for their future implementation on commercial farms. Therefore, in WP 5 selected agricultural measures with a high GHG mitigation potential will be subject to economic assessment. The costs of GHG mitigation measures for farmers will be calculated. An economic model deriving costs of implementation of GHG mitigation measures will be developed. The model will consider investment costs as well as changes in direct costs, labour costs and economic yield. To provide appropriate information for decision makers, costs will be contrasted with GHG mitigation potentials and the most relevant cost factors will be pinpointed.

Results from WP 2, 3, 4, and 5 will be used in WP 6 to find potential for improvement of reporting to UNFCCC and reduction of uncertainties. The Austrian National Inventory Report (NIR) provides a detailed and comprehensive description of the methodologies applied in the Austrian greenhouse gas inventory for the gases of the "Kyoto basket" (CO_2, CH_4, N_2O, HFC, PFC and SF6). At present, no national methodology is used for nitrous oxide emissions. Thus, the default emission factors, according to IPCC 1997, must be used. The IPCC good practice guidance recommends, however, application of higher tier measures to relevant source categories (so called key categories), so methodological improvements would follow this recommendation.

The results of the more precise calculation method (national EF for nitrous oxide emissions from WP 4) will be compared with the status quo of the National Inventory Report - regional (national) N and GHG fluxes in animal husbandry, crop production and soil management will be recalculated with the improved model results. The results will also be compared with the outcomes in relevant international literature, which is highly diverse in this regard.

It is of great concern to the researchers involved in FarmClim to have their research results implemented on commercial farms. Only then will the environment benefit from research results. This requires close cooperation with stakeholders and the agricultural extension service. This close cooperation must start at an early stage of the measurement proposal. It is crucial to integrate the stakeholders` views into concepts for environmentally-friendly management options. There is a range of aspects to be considered from the stakeholders´ perspective that scientists are not likely aware. The environment will only benefit when researchers and practitioners communicate and cooperate more closely. This will be done in WP 7.

2. OUTLOOK: FarmClim started in May 2012 and will continue for 24 months. The conference paper gives a detailed outline of the project and informs the scientific community at an early stage to foster communication and discussion. FarmClim assesses N and GHG fluxes in Austrian agriculture and proposes measures for

improvement. These measures will undergo an economic assessment. The IPCC default emission factor for soil N_2O emissions will be reviewed and improved, including the development of regional concepts to implement mitigation measures. IPCC reporting will be improved and uncertainties reduced. FarmClim covers the topic in a multi- and interdisciplinary approach, including nationally and internationally highly recognised experts from science, reporting and commercial farming. The inclusion of stakeholders` views at an early project state will contribute significantly to closing the science-policy gap in the field of climate-friendly farming.

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EFFECT OF A FEED ADDITIVE FROM PLANT RESIDUES ON GASEOUS EMISSIONS FROM STORED RABBIT MANURE

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ABSTRACT: Animals are often indicated as major sources of Green House Gas (GHG) emissions, not only from their metabolic processes but also from manure storage and use. Therefore, a trial was developed to evaluate the effect of a feed additive on gaseous emissions from manure during storage. Investigated emissions were CH_4, N_2O, and NH_3. The manure was produced from 3 groups of fattening rabbits fed with iso-energetic and iso-nitrogenous diets, supplemented with different amounts of an acid-insoluble compost extract. CH_4, N_2O, and NH_3 emissions from manure were measured at room temperature by a dynamic chamber method using a gas trace analyser. Emissions were recorded during a 25 d period, and referred to kg/min. Data were analysed by univariate GLM according to diet, time and their interaction, and differences were tested by Duncan's test. Emissions were different between diets in CH_4, and NH_3, while no differences were found in N_2O. Emissions of the three gasses also changed during storage ($P \leq 0.001$), with interaction between diets and time ($P \leq 0.001$). In detail, the highest emission values were recorded at the beginning of the storage period (day 0 for N_2O, and day 2 for CH_4 and NH_3), while the lowest were recorded in the 2nd part of the period (day 14 for CH_4, and day 22 for NH_3 and N_2O), but not at the end of storage (day 25). The use of this feed additive seems able to reduce GHG emissions from rabbit manure.

Keywords: GHG, CH_4, N_2O, NH_3

INTRODUCTION: Animals release a significant amount of acidifying and Green House Gases (GHGs) into the atmosphere, produced both directly from their metabolic processes and indirectly from manure storage and spread. Several substances are reputed able, for their properties, to reduce gaseous emissions, modifying the gastro-intestinal environment and the faeces chemical composition. Among these compounds the acid soluble bio-organic substances (SBO) isolated from gardening compost and park trimming residues are reported to have promising performances for several uses (Montoneri *et al.*, 2011), including monogastric animal nutrition (e.g. pig and poultry), acting on intestinal mucosa and microflora, as found for similar substances isolated from peat (Kloecking and Helbig, 2005, Islam *et al.* 2005). Among livestock, rabbits have a particular digestive metabolism that differs from others studied. Therefore, a trial was developed to evaluate the effect of SBO feed addition to rabbit diet on major GHGs (methane, CH_4; nitrous oxide, N_2O) and ammonia (NH_3) emissions from manure during storage.

1. MATERIAL AND METHODS: The tested animals were rabbits for their particular digestive metabolism, and also for their short production cycle and low cost.

1.1. Samples collection: The manure was produced from 3 groups of fattening rabbits fed with iso-energetic (DE = 11.2 MJ/kg DM) and iso-nitrogenous (CP = 17.8% DM) diets, supplemented with different amounts (C, control: 0%; L, low: 0.05%; H, high:

0.25%) of SBO extract from plant residues, which is supposed to improve animal performance and to modify nitrogen utilisation and livestock gas emissions.

1.2. Gaseous emission measurements: CH_4, N_2O, and NH_3 emissions from manure (0.50 kg of faeces and urine mix in a 1:4 ratio as wet:wet weight, in 1.5 L vessels with diameter of 11.3 cm) were measured at room temperature (24.4±1.6 °C) by a dynamic chamber method using a gas trace analyser (1412 Photoacoustic Multi-gas Monitor, Innova Air-Tech Instruments), following Dinuccio *et al.* (2008). Emissions were recorded in 21 sessions on six replicates for diet during a 25 d period, and referred to kg/min.

1.3. Statistical analysis: Data were analysed by univariate GLM according to diet, time and their interaction, and differences were tested by Duncan's test (SPSS, 2008).

2. RESULTS AND DISCUSSION: As shown in Table 1, average gas emissions during storage were different between diets in CH_4 and NH_3, while no differences were found in N_2O (Table 1). This effect must be due to microbial interaction with SBO. In addition, substances similar to SBO, such as humates, have shown to be inhibitory or stimulating the microbial growth, and consequently, the microbial enzymes production. The extent of these effects can be quite large depending on the species, the culture medium and the environment (Huch *et al*., 1991). Regarding N_2O release, the absence of statistical differences between the tested groups could be imputable to the factors affecting the N_2O release that is notably high after application to cropland or deposition on grazing land, showing instead a wide variability during the storage phase (Smith *et al.*, 2007).

Table 1. Gas emissions (mean ± s.d.) from rabbit manure from different diet SBO addition (control, C: 0%; low, L: 0.05%; high, H: 0.25%) during a storage of 25 d.

Gas emission	Diet treatment		
	C	L	H
CH_4 (mg/kg/min)	0.022±0.009 ^{A}	0.020±0.010 ^{A}	0.017±0.007 ^{B}
N_2O (μg/kg/min)	0.799±0.364	0.818±0.347	0.829±0.334
NH_3 (mg/kg/min)	0.110±0.032 ^{A}	0.106±0.035 ^{A}	0.082±0.025 ^{B}

Data in a row followed by a different capital letter differ for $P \leq 0.001$.

2.1. Gaseous emission trend: Emissions of the three gasses also changed during storage ($P \leq 0.001$), with interaction between diets and time ($P \leq 0.001$). As shown in Figure 1, the highest emission values were recorded at the beginning of the storage period (day 0 for N_2O, and day 2 for CH_4 and NH_3), while the lowest were recorded in the 2nd part of the period (day 14 for CH_4, and day 22 for NH_3 and N_2O), but not at the end of storage (day 25).

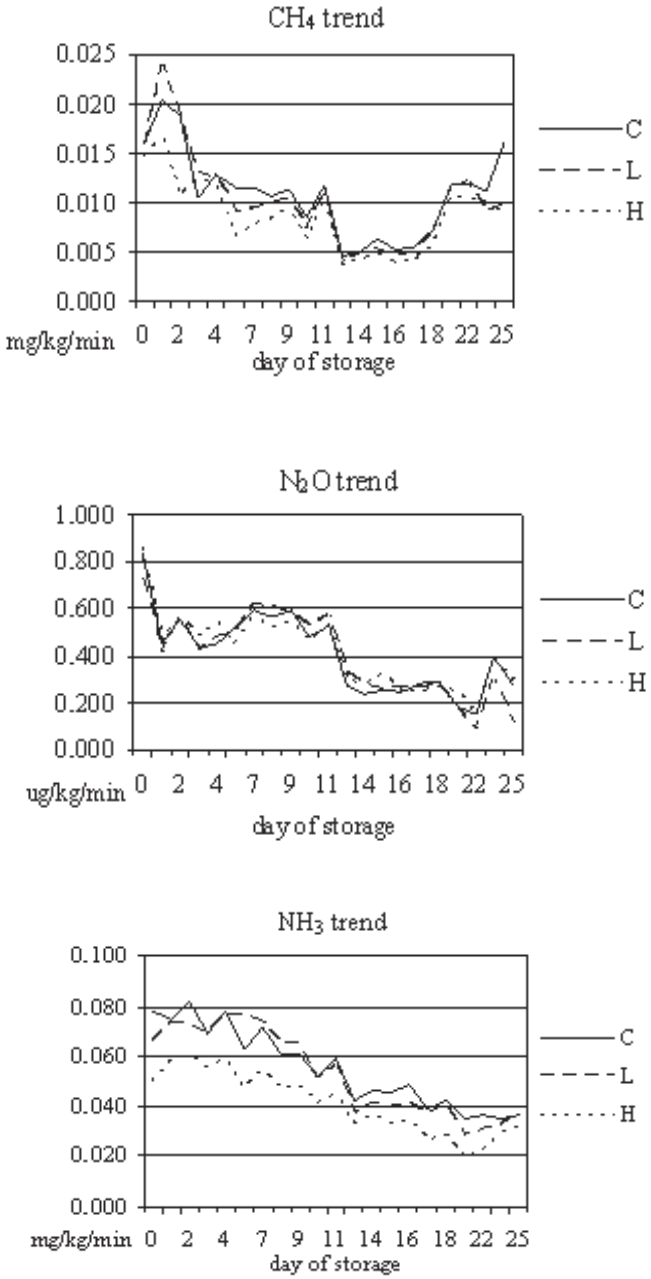

Figure 1. Emission trend for CH_4 (mg/kg/min), N_2O (μg/kg/min) and NH_3 (mg/kg/min) from rabbit manure deriving from different diet SBO addition (control, C: 0%; low, L: 0.05%; high, H: 0.25%) during a storage of 25 d.

CONCLUSION: The use of SBO as a feed additive seems able to reduce GHGs or acidifying gas emissions from rabbit manure without affecting animal performance. It is possible that a higher SBO level of integration in the diet could also have effects on rabbit growth or feed efficiency, as on different levels of gas emissions, but further studies are required to better understand the present results and SBO effects at different concentrations.

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FEEDING MEASURES TO REDUCE AMMONIA EMISSIONS

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ABSTRACT: Feeding measures are an important element of strategies to reduce ammonia (NH_3) emissions and, more generally, to reduce nitrogen (N) turnover and improve N-efficiency of livestock farms. For monogastric animals, the diet can be "tailored" to optimum CP level and the effect on emissions can be reliably predicted. A national Swiss survey on pig feeding showed that a diet with reduced protein, as is already used for ~70% of the production, can reduce ammonia emission by 13-17% for fatteners and by 8-11% for sows compared to traditional "standard feed". Subsequent implementation of phase feeding could further reduce emissions. For ruminants, low-emission feeding strategies are more challenging because the roughage intake and its protein content are variable and can be manipulated only to a limited extent, especially in countries like Switzerland with high use of herbage and relatively low concentrate use. Supplementing grass diets during summer with low-protein forage such as hay or maize and limited grass silage use in winter are promising strategies. Model calculations for different dairy cow diets showed a span of total annual excretion per cow of 102-139 kg total N, 52-87 urinary N and 32-48 kg total ammonia N emissions. Overall, a reduction of N excretion by 1 kg leads to a reduction of 0.47 kg urinary N and 0.42 kg ammonia N emissions. Full grazing systems (>20 h per day) could further reduce annual emissions per cow to 25-28 kg N, depending on the protein content of the grass.

Keywords: ammonia emissions, feeding measures, pigs, dairy cattle, model calculations

INTRODUCTION: Feeding measures are an important element of strategies to reduce ammonia (NH_3) emissions and, more generally, to reduce nitrogen (N) turnover and improve N-efficiency of livestock farms. They are therefore important both from the environmental and economic perspective. The basic approach consists of the following elements: 1) avoid crude protein (CP) surplus through diets matching animal requirements, 2) limit protein intake by improving the protein quality (use of pure amino acids; particularly for monogastric animals), 3) reduce the imbalance of ruminally available protein and energy by choosing appropriate feed components for ruminants. Production systems with emphasis on grazing are a further option to reduce NH_3 emissions from herbivores.

In Switzerland several cantons have recently introduced "resource programmes" which give incentives to farmers for special efforts to reduce environmental impacts of agriculture. Apart from low manure spreading techniques with reduced emissions, several of these programmes also aim to include feeding measures.

1. MATERIAL AND METHODS:

1.1. Survey on pig feeding practice in Switzerland in 2008: To gain an overview of the current pig-feeding practices in Switzerland, a survey was conducted based on

data from manufacturers comprising 70-80% of the Swiss pig-feed market. Overall, 1500 feed brands were included in the survey. Based on feed specifications and sale volumes, usage of NPr-feed (nitrogen and phosphorus (P) reduced feed) and average nutrient content of pig feeds were calculated. To verify if declared diet specifications corresponded with actual concentrations, declared and analyzed data from 108 diets were compared. Additionally, the import-export balance data of 1665 pig farms in the Canton of Luzern, an area with especially high livestock density, was analyzed.

To assess the potential of reducing ammonia emissions through pig feeding measures, model calculations were done with the emission model Agrammon (Kupper et al., 2010), using the results of the survey and different scenarios of reduced protein content and feeding regimes.

1.2. Model calculations for dairy cow diets: For model calculations on excretions of dairy cows with different rations and feeding regimes, we used the feeding model developed by Münger (2010, personal communication) which is based on the official Swiss feeding recommendations (RAP 1999), which includes a feed intake model, and the Swiss Feed Database (www.feedbase.ch). For the purpose of our study the Münger model was extended. The ruminal balance (PMN – PME= microbial protein from N minus microbial protein from fermentable organic matter) was added as an additional feed characteristic, and N excretion in feces and urine was differentiated based on regressions on the fecal N digestibility derived from N balance studies. Different typical summer and winter diets, with and without silage, were defined and calculated with the model in different combinations. The main scenarios were calculated for an annual milk yield per cow of 7000 kg ECM, calving in October, CP content of the grass in summer of 21%, and length of winter feeding-period 154 days. In additional scenarios, milk yield, the calving date, the grass CP content and complementary feeding were individually varied.

For emission calculations, the model Agrammon (Kupper et al., 2010) was used, which calculates emissions along the N flow using emission factors in percent of TAN (total ammoniacal N). It was assumed that 100% of the N excreted in urine is equivalent to TAN. To focus on the effect of feeding, all other emission variables were defined as constant, such as housing, storage and slurry application (see legend Tab. 1).

2. RESULTS AND DISCUSSION:

2.1. Results for pigs: In 2008, approximately 70% of the compound feed for fattening pigs sold in Switzerland was already NPr, with regional differences. In the Canton of Luzern, the NPr market was well above 90% because farmers needed to meet the required nutrient (N and P) balance without reducing animal numbers. However, P was often reduced more than CP. While the CP content of the standard feed for fattening pigs was on average 17.3%, it was 15.8% for NPr. The analysis revealed no protein over-formulation compared to the declared values. Phase feeding is not yet well established in Switzerland. While phase feeding in sows attains a level of 68%, only 10% of the compound feed for fattening pigs clearly belong either to the grower- or finisher-feed category. However, farmers often apply a form of short-cut phase feeding. They start the fattening period with a starter feed for 3 weeks, which is then replaced by a grower-finisher feed (universal feed) that is maintained until slaughter. Because the average farm size is relatively small, it would be difficult to organize the delivery of phase feeds in such a way that the farmers can still benefit from quantity discounts. Also farmers would require additional feed silos.

A dietary change to NPr feeds by the remaining 30% of the Swiss pig farms still using standard feeds would reduce NH_3 emissions by about 10%. The emission reduction potential when switching from standard to NPr feed varies depending on the production system: 13-17% for fattening farms from and 8-11% for sow units.

2.2. Results for dairy cows: For ruminants low-emission feeding strategies are more challenging because the roughage intake and its protein content are variable and can be manipulated only to a limited extent. This is especially important in countries like Switzerland, with high use of herbage and relatively low concentrate use. The main feeding strategies consist of reducing protein imbalances by 1) supplementing fresh grass diets with low protein forage such as hay or maize or modifying the herbage quality; 2) avoiding a high proportion of grass silage during the winter feeding-period; 3) increasing grazing during summer, because urine infiltrates into the soil before urea is degraded to TAN; or 4) feeding year-round a total mixed ration (TMR, e.g. with maize silage, grass silage, hay, beet residues).

Dietary differences have practically no influence on N excretion in feces but are clearly visible in N excretions in urine (Table 1). Supplementation of fresh grass with low protein forage such as hay or maize can reduce annual emissions by 4-6%. Differences in the winter diet can have a more pronounced effect on emissions, mainly depending on the proportion of grass silage in the diet. A ration without silage (required for non-pasteurized cheese production) and a ration with maize and grass silage plus hay lead to the same emissions level, while a ration with grass silage and hay causes approx. 10% higher emissions. Additional grazing also has a clear effect on emissions. For 12 h grazing instead of 6 h, annual emissions would be reduced by about 20%, for 16 h 30%, for 20 h over 40% and for 24 h over 50%. The TMR which achieves a good protein/energy balance over the whole year leads to 25% lower annual emissions than the rations with fresh grass only and with maize silage restricted to the winter feeding-period. It must be noted that the rations used contain low concentrate amounts (320-560 kg for the 7000 kg yield) because most farms try to minimize the amount of relatively costly concentrate and make optimal use of their own roughage resources. The Swiss forage quality (especially hay and grass silage) is also quite high in NEL and APD, requiring less concentrate than in countries using high amounts of concentrate.

For the full grazing regime (animals grazing for >20 h/day during the entire grazing season; calving period in February) emissions would be approx. 30% lower than for the corresponding scenario with 6 h/day grazing. Even in the case of a high CP content in the pasture grass of 24.5%, the reduction in NH_3-N emission still is 20%, in spite of the increase in total N excretion of 25%.

Table 1. Annual N excretions in kg per cow (feces, urine, total) and NH_3-N emissions for different combinations of winter and summer period diets. Assumptions: 7000 kg milk yield, calving in October, 6 h/day grazing during summer feeding-period (211 days), CP content of grass 21%, loose housing system with slurry production, closed slurry store, splash plate slurry spreading. G – grass, H – hay, MS – maize silage, MP – maize pellets, GS – grass silage, BR – sugar beet residues, TMR – total mixed ration with MS/GS/H/BR.

Winter diet	85% H, 15% fodder beets			85% H 15% MP	50% H 50% GS		40% MS 40% GS 20% H	TMR
Summer diet	G	G, 10% H	G, 10% MP	G, 10% H	G	G, 10% BR	G, 15% MS	TMR
N feces	51,3	50,9	51	51,1	50,1	50,5	50,2	49,7
N urine	78,8	73,9	73,4	77,8	87,3	82,8	75,2	52,1
Total N excretion	130,1	124,8	1244	128,8	138	133,2	125,4	101,8
Emissions	42,8	40,4	40,1	42,9	48,2	45,9	41,6	31,7

CONCLUSIONS: For pigs, most farms already use feed with reduced CP content because of crop nutrient-balance limitations. However, a further decrease in NH_3 emissions would still be possible, even for these farms, by further reducing the CP content in dry sow feeds and switching to phase feeding in all pig categories.

For dairy cattle, there are two strategies which could bring a substantial reduction of NH_3 emissions: 1) use of "total mixed rations" with well balanced protein/energy ratios over the whole year and 2) full grazing systems, in which animals graze for the entire summer feeding-period (>20 h/day for milked cows). Both solutions would have the advantage that their effect can be reliably quantified and their implementation is controllable. However, they are not realistic for a majority of the farms for structural and market reasons. In addition, full grazing systems reduce whole farm N-efficiency and increase the risk of nitrate leaching. Another effective strategy would be to increase concentrate use to balance the protein/energy ratio of the grass and grass-silage-based rations. However, this is contradictory to the concept of grassland-based milk production and hardly realistic for most farms because they have to utilize their grassland.
Supplementation of the fresh grass diet with low-protein forage such as hay or maize only has a limited potential to reduce emissions. However, if most farms would implement this strategy the effect on total emissions would still be considerable because of the large contribution of cattle to the total amount of N in manure. However, the effect of such measures cannot be reliably quantified. For consideration in resource programs, indicators such as milk urea content, for example, would have to be used.

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EFFECT OF WATER ADDITIVES ON AMMONIA EMISSIONS FROM BROILERS

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ABSTRACT: Consumption of broiler meat has increased rapidly in Europe over the past several years. Associated ammonia (NH_3) emissions arising from broiler rearing are of great environmental concern. The objective of this study was to determine the effect of a liquid water additive made of seaweed (Biopolym®). The investigated barn was separated into two halves. During the 36-day growing cycle, broilers in one half were provided with water enriched with Biopolym®. The broilers in the other half received only plain water. In both halves of the barn, the NH_3 mass-flow rate was measured. Additionally, water and feed consumption of the broilers were recorded. The results showed that the cumulative feed intake of the broilers was 3.19kg broiler^{-1} taking the water enriched with Biopolym® and 3.34 kg broiler^{-1} taking plain water. The water intake followed similar trend as feed intake, which was 5.54 l broiler^{-1} drinking water enriched with Biopolym® and 5.77 l broiler^{-1} drinking plain water. Without the water additive, broilers emitted 140.1 kg NH_3-N over the growing cycle. In contrast, detected NH_3-N emissions from the broilers drinking the water enriched with Biopolym® decreased by about 38% (86.8 kg). The outcome of this study illustrates that it is worth investigating further the impacts of the liquid water additive in reducing NH_3-N emission, with the aim of a sustainable broiler production.

Keywords: NH_3, broiler, water additive, mitigation strategy

INTRODUCTION: In Europe, the livestock sector has rapidly increased over the past several years due to a growing demand for meat. Broiler operations have become larger and more concentrated (Steinfeld & Wasenaar, 2007). Meanwhile broiler meat occupies second place in worldwide production volume (Niu et al., 2009). The results have been a greater concentration of nutrients in the form of waste products such as manure (litter) and gaseous emissions (Gous, 2010). In particular, ammonia (NH_3) emissions may cause harmful effects on the environment, such as acidification of soils, increased eutrophication of water bodies, degraded forests or decreased biological diversity (Krupa, 2003). Ammonia is formed from the breakdown of nitrogenous waste products in broiler manure (undigested proteins and uric acid) by enzymes produced by microorganisms. One of the abatement strategies for NH_3 emission is optimisation of dietary composition by meeting the nutrient requirements of broilers while minimising manure excretion (Robertson et al., 2002). By using additional feed additives, the feed conversion rate of broilers is expected to improve (Ritz et al., 2004).

The objective of this study was to determine the effect of a liquid water additive on broiler performance and emissions.

1. MATERIAL AND METHODS:

1.1. Study site: The study was carried out during an entire 36-day growing cycle in 2010. About 57,000 commercial broilers were raised in a barn (length: 93 m, width: 29 m and height: 4.5 m). The barn was divided into two pens of 28,500 broilers each. In each pen, the broilers were provided with ad libitum access to feed and water. A

multiphase feeding regime consisting of four diets supplied by a commercial integrator was fed over the growing cycle of 36 days to a market mass of approximately 1.8 to 2.1 kg. In one pen, water supplemented with a liquid additive made of seaweed (Biopolym®) was provided 15 days after starting the growing cycle (treated group; pen 2). In the other pen, the broilers received only plain water (control group; pen 1). Broilers were weighed in-house on permanently installed electronic scales. Mortalities were recorded and removed out of the barns daily. The mechanical ventilation system was controlled by the inside air temperature of the broiler barn, which varied 22-34°C, depending on the age of the broilers.

1.2. Measurements: Inside the two broiler pens, the NH_3 concentration (cin in mg m^{-3}) and the airflow rate (q in m^3 h^{-1}) were measured by a photoacoustic multi-gas analyser (INNOVA AirTech Instruments; Type 1312) and by ventilators (Hotraco Group; Type MVP63) respectively. The sampling of NH_3 took place close to the exhaust-air outlets at the bottom of the rooftop stacks (six places in each pen), whereby the gas was sucked through PTFE-hoses to the multi-gas analyser. The NH_3 mass-flow (m) was calculated as Eq. (1):

$$m = c_{in} * q \qquad (1)$$

To estimate the nitrogen (N) loss from NH_3 emissions, a factor of 14/17 (0.824) was used as the difference in molecular weight between N and NH_3.

2. RESULTS AND DISCUSSION:

2.1. Broiler performance: During the first week of the growing cycle, 28,500 broilers of 175 g each were kept in each pen. The cumulative feed intake in both pens increased over the five weeks of growing cycle. In pen 2m where water enriched with Biopolym® was offered, the cumulative feed intake of the broilers was 3.19 kg broiler^{-1}. In contrast, the cumulative feed intake in pen 1 (plain water) was higher: 3.34 kg broiler^{-1} during the growing cycle. A similar trend was observed for water intake, which was lower (5.54 l broiler^{-1}) for broilers that drank water enriched with Biopolym® than those that drank plain water (5.77 l broiler^{-1}). Thus, by applying the water additive Biopolym®, feed and water intake were reduced by 4.7% and 4.0%, respectively.

2.2. NH_3 emissions: Directly measured airflow rates and the concentrations of NH_3 were used to calculate NH_3 mass-flows (Eq. 1), which increased during the 36 days of broiler rearing (Fig. 1). The increased NH_3 mass-flow (m) over the growing cycle is consistent with studies of Redwine et al. (2002). The average NH_3 emissions over the growing cycle (considering mortality) were 4.6 g broiler^{-1} and 7.1 g broiler^{-1} for pen 2 and pen 1, respectively. Previously, the NH_3 emission rates for the same barn was 2.4 g broiler^{-1} for whole growing cycle (von Bobrutzki et al., 2011). Guiziou and Beline (2005) reported an average emission rate of 5.74 g NH_3 per broiler for a 35-day growing cycle. These varying values can be explained by changes in temperature due to different seasons of the year among the experiments. Nevertheless, NH_3 emissions from different broiler barns can differ widely. Calculated from the sum of m (mass-flow), cumulative emission of NH_3-N from the broilers without the water additive was 140.1 kg over the growing cycle (Fig. 1). In contrast, NH_3-N emissions from the broilers drinking the water enriched with Biopolym® were decreased about 38% (53.4 kg). The positive effects observed of the water additive can help to reduce

NH_3-N emissions and increase broiler performance. Thus, these findings encourage further investigations for improving broiler production in a sustainable manner.

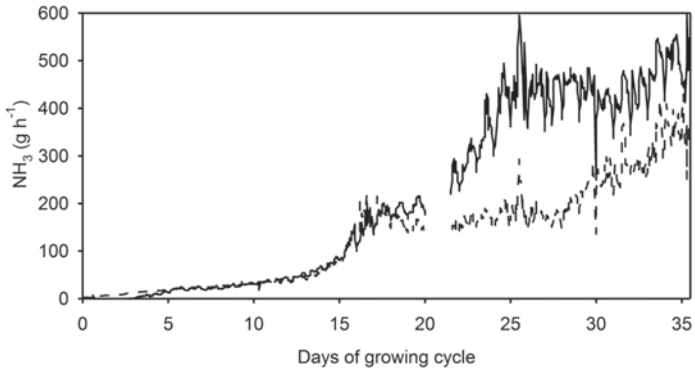

Figure 1. Time-series of NH_3 mass-flow (m) from both pens with 28,500 broilers each. The solid line shows the control group in pen 1 and the dashed lines indicates the treated group in pen 2.

CONCLUSION: During this study the effects of a water additive (Biopolym®) towards broiler performance and NH_3 emissions were explored. The water additive had a positive impact on broiler performance and litter conditions. Feed and water intake was reduced by 4.7% and 4.0%, respectively. The cumulative emission of NH_3-N from the broilers drinking the water enriched with Biopolym® were decreased about 38% (53.4 kg). Further investigations are necessary to confirm these findings.

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ABATEMENT OF AMMONIA EMISSIONS FROM A DAIRY BARN BY EXHAUST AIR CLEANING

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ABSTRACT: Dairy cows have the largest per animal emission of ammonia (NH_3) due to the energy and protein required for milk production. Emitted NH_3 can cause harmful environmental impacts such as eutrophication and acidification of ecosystems. The present study aims to define a model of a barn of 200 cows with constant 10°C air temperature and 80% relative air humidity inside the housing. A ventilation concept was developed according to recommendations of CIGR and animal welfare guidelines. The resulting airflow rates range between 22,000 and 100,000 $m^3\ h^{-1}$ for 200 cows, which involve N concentrations of 19.6 and 4.3 ppm, respectively. Ammonia-loaded exhaust air can be treated efficiently and cost-effectively by a biological-chemical technique in form of a trickle bed reactor. For an efficient operation, it is necessary to create optimum pH values to neutralise acidic and alkaline metabolic products. Further, to achieve a 70% N degradation rate, a sufficient sludge removal rate of the polluted water is necessary. Assuming a yearly release of 14.6 kg N per dairy cow, an emission reduction of 10 kg N per dairy and cow can be achieved by implementing a biological treatment of the exhaust air. One must also consider the amount of wash water, which ranges between 583 and 874 m^3 for 200 cows per year.

Keywords: cattle, NH_3, exhaust air cleaning, mitigation strategy

INTRODUCTION: In Europe more than 90% of atmospheric ammonia (NH_3) is caused by agricultural emissions, especially from livestock facilities (Erisman et al., 2008). Dairy cows have the largest per animal emission of NH_3 due to the energy and protein required for milk production (Zhang et al., 2005). Emitted NH_3 can cause harmful environmental impacts such as acidification of soils, enhanced eutrophication of water bodies, forest decline and decreasing biological diversity (Krupa, 2003). The housing systems used for dairy cows should provide a healthful and comfortable environment for the animals, which enables them to produce good-quality milk (Lindley & Whitaker, 1996). The ventilation system should be constructed in a way to maintain the desired environmental conditions inside the barn. Currently, natural ventilation systems represent the typical design of dairy buildings. Therefore, it is impossible to maintain constant environmental conditions inside a barn or to control NH_3 emissions. Compared with this, a controlled air flow by mechanical ventilation provides constant environmental conditions inside the barn and enables the processing of exhaust air to reduce NH_3 emissions.

The present paper aims to provide basic calculations of a forced ventilated barn with 200 dairy cows and the related exhaust air cleaning system.

1. MATERIAL AND METHODS:

2.1. General approach and animal performance: A simple balance model was developed to calculate and define basic parameters for a forced ventilated barn of 200

dairy cows for heat, moisture, waste gases and assumes ideal mixing conditions. An important prerequisite was the assumption of a constant 10°C air temperature and 80% relative air humidity inside the barn, which represents optimal living conditions for high-performance dairy cows. These air conditions can be achieved by implementing a forced ventilation system and a controlled air flow. To calculate applicable ventilation rates, meteorological data were used from the last 30 years for Potsdam (Germany). In this period, the ambient air temperature ranged between -20.7 and 38.6°C with varying air humidity.

According to CIGR recommendations (1984), a dairy cow releases 1156 W heat and 372 g h^{-1} water vapour (10,000 kg milk $year^{-1}$, body mass: 600 kg). To guarantee a sufficient air exchange rate, a minimum rate was defined to keep CO_2 concentrations below recommended harmful limits (5 g CO^2 kg^{-1} air according to CIGR, 1984). In addition, the NH_3 concentrations were also considered and set to a maximum limit of 20 ppm (according to German animal welfare guidelines). According to recommendations of the German Technical Instruction on Air Quality Control (TA-Luft, 2002), a release of 14.6 kg NH_3 per dairy cow and year was assumed.

2.2. Processing of exhaust air: The guidelines VDI 3478-2 (2008) and KTBL-Schrift 451 (2006) apply to the reduction of organic emission components that biodegrade NH_3 at sufficient speed. A biological trickle bed reactor represents an approved method for cleaning exhaust air polluted with gaseous substances foreign to air. It consists of packing with a film of microorganisms populating its surface. To provide the moisture of vital importance to the microorganisms, the packing is regularly sprayed with a film of liquid. To attain an efficient operation, it is necessary to keep the pH of trickling water constant between 6.5 and 7.5. Then, a NH_3 degradation rate of 70% can be achieved. Accordingly, the sludge removal rate of the polluted water varies between 0.2 and 0.3 m³ per kg NH_3 input.

2. RESULTS AND DISCUSSION:

2.1. Calculation of ventilation: Considering the release of heat and water vapour together with the emission of CO_2 from the 200 dairy cows, the following control system for the ventilation of the barn arises (Fig. 1).

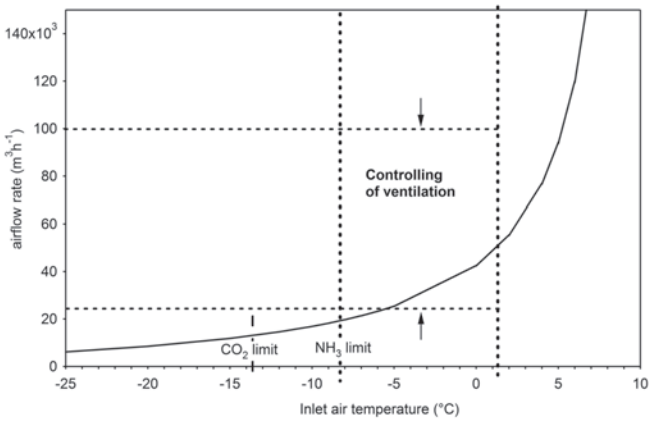

Figure 1. Scatter plot of airflow rate vs. inlet air temperature and determination of minimum and maximum airflow rates for the 200-dairy cow barn.

By applying the balance model, the environmental conditions inside the barn can be maintained just by controlling the airflow rate, in principle. Therefore, a minimum and a maximum airflow rate were determined. The minimum airflow rate for 200 cows to maintain CO_2 concentrations below recommended harmful limits (5 g CO_2 per kg air according to CIGR, 1984) was calculated to 15,000 m³ h^{-1}. This airflow rate corresponds to a -12°C inlet air temperature to maintain the barn conditions. Owing to the additional consideration of the German animal welfare guidelines, NH_3 concentrations should not exceed the limit of 20 ppm. As a consequence, the minimum airflow rate resulted in 22,000 m³ h^{-1} representing a -6°C inlet air temperature to maintain the inside air temperature. The corresponding maximum airflow rate was defined to 100,000 m³ h^{-1} which equates a 5°C inlet air temperature. Thus, in the range between 22,000 m³ h^{-1} (-6°C) and 100,000 m³ h^{-1} (5°C), the air conditions inside the barn can be controlled just by varying the airflow rate (marked with arrows in Fig. 1).

2.2. Criteria for biological trickle bed reactor: For the design of biological trickle bed reactors, many variables must be known. For instance, the range of airflow rate, the temperature and relative humidity of the exhaust gas and occurring concentration of NH_3 are important. For an efficient operation, it is necessary to create optimum pH values for neutralising acidic and alkaline metabolic products. To achieve a 70% NH_3 degradation rate, a sufficient sludge removal rate of the polluted water must be warranted. Table 1 shows important variables for dimensioning a biological trickle bed reactor that can be integrated into the concept of a forced ventilated barn of 200 cows. Finally, the implementation of a mechanical ventilation system offers the opportunity to process the exhaust air and reduce NH_3 emissions down to 4 kg NH_3 per dairy cow per year.

Table 1.Variables of reactor dimensioning valid for 200 cows.

Airflow rate (m^3 h^{-1})	22,000[1]	100,000[2]
Max. NH_3 (ppm)	19.6	4.3
Sludge removal rate (m^3)	584[3]	876[4]

[1] Minimum airflow rate
[2] Maximum airflow rate
[3] Assuming 0.2 m³ per kg NH_3 input
[4] Assuming 0.3 m³ per kg NH_3 input

CONCLUSION: This investigation arose from a feasibility study and basic calculations of a forced ventilated barn with 200 dairy cows together with an exhaust air cleaning system. According to CIGR recommendations and animal welfare requirements, the airflow rates range between 22,000 and 100,000 m³ h^{-1} to maintain constant conditions at 10°C and 80% relative humidity inside the barn just by controlling the ventilation. To improve the air quality in the vicinity of the dairy barn, an exhaust air cleaning system for reducing NH_3 should be installed. Initial calculations were performed to design a biological trickle bed reactor, which represents an approved method for cleaning exhaust air. Overall, the 70% NH_3 degradation rate can be achieved, which equates to an emission reduction of 10 kg NH_3 per dairy cow per year.

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POTENTIAL OF EXTRACTS FROM SAPONIN-CONTAINING PLANTS TO DECREASE IN VITRO METHANE AND AMMONIA PRODUCTIONS IN RUMINANTS

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ABSTRACT: Methane (CH_4) and ammonia (NH_3) are produced during rumen fermentation. Decreasing their production with saponins has shown technical (optimised feed utilisation) and environmental interests by orienting ruminal fermentation favourably. The aim of this study was to evaluate the ability of several extracts from saponin-containing plants to decrease in vitro NH_3 and CH_4 production in relation to their chemical profiles. Cultivars of saponin-containing plants harvested at the iteipmai technical institute (e.g. Calendula officinalis aerial part) and by-products rich in saponins (e.g. Chenopodium quinoa hulls) and sources of saponins previously described in animal nutrition (e.g. Quillaja saponaria wood) were also studied. Seventeen extracts were prepared by maceration. Chemical profile analyses were performed through HPLC-ESI-MSn. Extracts added to a standard feed were fermented in vitro with buffered rumen fluid. Saponins were identified as major compounds in the different extracts. Inhibition of NH_3 and CH_4 production started at 0.1 mg/mL and 0.2 mg/mL ($p<0.05$, Tukey Honestly Significant Difference), respectively. Regarding the results for all the extracts tested at 0.4 mg/mL, positive correlations were strong between protozoa number and NH_3 concentration ($R2=0.78$). Extracts of by-products showed a more pronounced effect towards NH_3 production when compared with saponin-containing plants commonly used in animal production (e.g., -30% for Chenopodium quinoa vs -23% for Quillaja saponaria). If results are confirmed in long term in vivo trials, new uses for food and horticultural industry wastes containing saponins might be explored.

Keywords: saponins, in vitro rumen fermentation, NH_3, CH_4, protozoa

INTRODUCTION: Plant-derived saponins are composed of a polar sugar moiety glycosidically linked to a non polar aglycone (terpenoid or steroid). CH_4 production from rumen fermentation is responsible for an energy loss and contributes to anthropogenic greenhouse gas emissions worldwide (Steinfeld et al., 2006). High-production diets or turn-out to grass are often the cause of an excess of NH_3 in the rumen, inducing excess nitrogen in dejections, which is detrimental to the environment (Castillo et al., 2001). The effects of commercially available saponin-containing plants such as *Yucca schidigera* and *Quillaja saponaria* on NH_3 and CH_4 production are well documented (Wina et al., 2005). Published data about other saponin sources are rare though saponins are widely distributed in plants. The objective of this study was to evaluate the effect of different extracts of saponin-containing plants, including *Y. schidigera* and *Q. saponaria*, but also less-studied botanical species, on the dynamics of NH_3, volatile fatty acids (VFA), CH_4 and

protozoa during *in vitro* rumen fermentation. The identification of the saponins was completed through HPLC-MS^n. Seventeen extracts from 11 plant species were evaluated.

1. MATERIAL AND METHODS:

1.1. Plant extracts: Aqueous extracts from floral heads of Calendula officinalis and Saponaria officinalis; roots of Calendula officinalis, Saponaria vaccaria, Gypsophilla paniculata and Primula veris; seeds of Trigonella foenum-graecum; meals of Argania spinonsa and hulls of Chenopodium quinoa; and hydroalcoholic extract of Saponaria officinalis roots were prepared by maceration. The solutions then were centrifuged, and the supernatants were collected. Liquid extracts were freeze-dried to create the powdered extracts used for the in vitro rumen fermentations. Syrup of Yucca schidigera was lyophilised. Yuquina® M, a commercial product from Nor-Feed Sud, and Quillaja saponaria extract standardized at 10% sapogenin from Sigma-Aldrich were used directly.

1.2. Identification of saponin compounds by liquid chromatography - mass spectrometry: Detection and identification of the saponins from samples were performed using an electrospray ionization-ion trap mass spectrometer coupled with a high performance liquid chromatography (HPLC-ESI-MS^n). Separation was performed on a C18 Luna column (150 mm x 4,6 mm, 5 µm) with water, acetonitrile and acetic acid.

1.3. In vitro rumen fermentation: Fermentations of 24 hours were performed according to the Hohenheim syringe-based *in vitro* gas method (López et al., 2010). Dried ryegrass (*Lolium perenne*) roughage and wheat (*Triticum aestivum*) seeds (70-30, w/w) composed the basal feedstuff (DM: 960 g/ kg, protein: 89 g/kg DM). Fermentation substrates were prepared by blending the extracts and the basal feedstuff (5-95 w/w DM). A control was composed of basal feedstuff only. The concentration of extracts in rumen fluid was 0.4 mg/mL, equivalent to 80 g/dairy cow/day. Dose-effect relationships were carried out on fermentations in culture bottles.

1.3.1. Rumen fluid analysis: Samples from incubation media were mixed with a methyl green-formalin solution (50-50, v/v). A generic protozoa profile was microscopically determined using a 10 µl Agasse Lafont counting chamber. Protozoa were identified and quantified according to Ogimoto and Imai (1981). Samples of rumen fluid were analyzed for NH_3 concentration by spectrophotometry and for total VFA by gas chromatography.

1.3.2. CH_4 production: Total gas volume was recorded from syringes after incubation. Gases were sampled in gas-tight vials. Gas composition was determined by gas chromatography coupled with a thermal conductivity detector. The production of CH_4 was calculated as: CH_4 (mL) = CH_4 concentration (%) × Total gas production (mL).

1.4. Statistical analysis: Mean comparison was performed by two-way variance analysis (ANOVA) with subsequent post-hoc multiple comparison test of Tukey-HSD (Honestly Significant Difference) using XLSTAT (version 2011.2.04, Addinsoft, USA). Treatment effects were declared significant at $P<0.05$, and trends were accepted at $P<0.10$.

2. RESULTS AND DISCUSSION:

2.1. Identification of saponin compounds by HPLC-MS^n: A total of 137 different saponins were detected with high HPLC-MS intensities. Among them 99 were identified through comparison of elution order, mass-to-charge ratio and fragmentation patterns (MS^2, MS^3 and if needed MS^4) with literature data. All the saponins appeared to derive from 33 different sapogenins. The number of saponins detected per extract ranged from 3 to 21 (Table 1). This chemical part of the work allowed us to associate each extract with a chromatogram and hence to gather pools of saponin compounds with biological activities.

2.2. Rumen-fluid analysis: No significant difference was observed for total VFA production and pH after 24 hours of fermentation. Concentration of total rumen protozoa was higher after fermentation than before (+43%). This was probably due to a relatively high pH (7.00 ± 0.06), as well as high levels of cellulose fibres and starch-grain substrate favourable to the growth of protozoa. Concentration of total rumen protozoa was significantly lower than the negative control for eight extracts (Table 1). It was the lowest in the syringes containing *P.veris* (0.41 ± 0.05 x10^5/mL on average, 51% lower than the control, $p<0.001$). No increase in total protozoa was observed. The decrease in total rumen protozoa was in accordance with the data available for *Y. schidigera* and *Q. saponaria* (Makkar et al., 1998).

With respectively 27, 31 and 30% inhibition ($p<0.05$), *G. paniculata, P. veris* and *C. quinoa* had a better effect on NH_3 production than commercial products based on *Y. schidigera* and *Q. saponaria* (23% inhibition, $p<0.10$). Total rumen protozoa concentration and NH_3 level from *in vitro* fermentation showed a positive, linear and significant correlation (Pearson coefficient = 0.77, $p < 0.001$) between variables. By lowering the predation activity of protozoa, extracts might promote higher NH_3 utilization by microbial protein synthesis and lower proteolysis of protozoal origin (Makkar et al., 1998). Previous works on ruminants demonstrating an improvement in microbial protein synthesis by adding saponins to the diet (Wina et al., 2005) confirm this interpretation of the protozoa-NH_3 correlation.

2.3. CH_4 production: At 0.4 mg/mL, no significant difference was observed in CH_4 production among the treatments (Table 1). It matches the literature regarding *Q. saponaria* but not for *Y. schidigera*. At 0.375 mg/mL, Holtshausen et al., (2009) observed a significant 8.5% decrease on *in vitro* CH_4 production with *Y. schidigera* but no significant effect with *Q. saponaria*. The absence of observed significant drops in CH_4 production may be due to a experimental design (triplicates) selected to work with many extracts, rather than assessing differences.

Inhibition of NH3 and CH4 started respectively at 0.1 mg/mL and 0.2 mg/mL ($p<0.05$, Tukey-HSD) with the Yuquina® M in culture bottles with a feedstuff based on grass silage, corn silage and concentrate (35-35-30, DM: 547 g/kg, proteins: 144 g/kg DM).

Table 1. Chemical and biological results of extracts from saponin-containing plants.

Plant extracts	Saponins detected	Replicates	Rumen protozoa[1]	NH_3[1]	CH_4[1]
P. veris	3	3	-57.4%[e]	-30.9%[c]	-3.3%
C. quinoa	11	3	-49.1%[de]	-29.8%[c]	-6.5%
G. paniculata	15	3	-23.1%[bc]	-27.2%[c]	-2.8%
Y. schidigera	17	3	-33.1%[cde]	-23.5%[bc]	-4.7%
Q. saponaria	21	3	-56.9%[e]	-23.3%[bc]	-1.0%
T. foenum graecum	11	3	-27.5%[cd]	-11.2%[bc]	+9.1%
S. vaccaria	8	3	-35.0%[cde]	-16.0%[bc]	-4.2%
A. spinosa	8	3	-33.8%[cde]	-7.0%[bc]	2.4%
Yuquina® M	21	3	-49.4%[e]	-4.6%[b]	-10.3%
Negative control		6	0%[ab]	0%[ab]	0%
S. officinalis (roots)	16	3	+6.7%[a]	+4.0%[a]	-9.0%
S. officinalis (aerial part)	9	9*	+4.8%[a]	+29.1%[d]	-3.1%
C. officinalis (aerial part)	4	9*	+10%[a]	+31.1%[d]	-4.2%
C. officinalis (roots)	3	3	+14.0%[a]	+31.4%[d]	-4.4%

[1]Data are the mean inhibition. Plant extracts ranked according to their potential to inhibit NH_3 production, *3 different extracts coming from 3 different cultivars were used, [abcde] different letters in the same column indicate statistical difference among the extracts ($p<0.05$ Tukey-HSD)

CONCLUSION: Only few extracts from saponin containing plants were able to mitigate ammonia and methane production in vitro. In vivo trials are necessary to confirm the potential of G. paniculata, P. veris and C. quinoa extracts as efficient feed additives in ruminants.

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GREEN HOUSE GASES AND AMMONIA EMISSIONS FROM TWO CONTRASTED DAIRY CATTLE DEEP LITTERS

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ABSTRACT: Animal housing contributes a large proportion of greenhouse gases (GHG) and ammonia emissions in livestock systems. The diversity of the French cattle systems is huge mainly because of the many manure management systems (with or without straw). The aim of this study is to provide knowledge on GHG and NH_3 emissions to propose mitigation options. During, respectively 4 (P1) and 6 (P2) weeks, two deep litters were accumulated beneath three dairy cows in a mechanically ventilated room, with different animal stocking densities; 9.7m^2 per cow in P1 and 12.4m^2 per cow in P2 . During accumulation of the litter, we continuously measured the emissions of CO_2, N_2O, CH_4, and NH_3. The deep litter in P1 was more humid (20.1% DM) than in P2 (27.2 %DM). The deep litter in P1 produced less N_2O but more CH_4 and NH_3 than in P2. Means emissions were, respectively, 8214 g/day/cow, 0.433 g/day/cow, 713 g/day/cow, and 97 g/day/cow for CO_2-C, N_20-N, CH_4-C and NH_3-N in P1 and 8048 g/day/cow, 0.468 g/day/cow, 627 g/day/cow, and 56 g/day/cow in P2. These results (i) improve our understanding of emitting processes related to deep litters; (ii) highlight that too high animal stocking density on deep litter will lead to higher GHG and ammonia emissions. In that sense, both animal welfare and environmental issues recommend lower stocking densities for dairy cattle.

Keywords: emissions, NH_3, GHG, deep litter, dairy cow

INTRODUCTION: Animal housing contributes a large proportion of GHG and ammonia emissions in livestock systems. French cattle systems show a large diversity of housing, most of them based on litter (55% of dairy cows in 2008, France). Many studies have already been done on slurry systems but data regarding farm yard manure (FYM) systems are lacking. The aim of this study is to better understand GHG and ammonia emissions from deep litters to find mitigation options that reduce polluting emissions.

1. MATERIAL AND METHODS:

1.1. Description of the experimental design: During, respectively 4 (P1) and 6 (P2) weeks, two deep litters were accumulated beneath three dairy cows in a climatic room with dynamic ventilation, with different animal stocking densities: 9.7m^2 per cow in P1, 12.4m^2 per cow in P2 (which is close to the recommended values for dairy cows on deep litters; 10 m^2 per cow). At the end of the accumulative period, after the three cows left the room, the litters remained in the room for a few days. More details on the two experimental periods are given in Table 1.

Table 1: Main characteristics of the 2 experimental periods, P1 and P2.

	Period 1 (P1)	*Period 2 (P2)*
Duration (days)	37	49
Beginning of the measurement	14/09/2010	01/11/2010
End of the measurement	20/10/2010	19/12/2010
Duration of accumulation of the litter under the cows (days)	29	44
Number of cows	3	3
Area of the litter (m^2)	29.24	37.22
Straw supply (kg/day)	37.8	40.0

1.2. Emissions measurement devices During accumulation of the litter, we continuously measured the emissions of CO_2, N_2O, CH_4, and NH_3. Ventilation rates were estimated using the gas (SF_6) tracer method (Phillips et al., 2000). Gas concentrations were continuously measured outside and inside the rooms with an infrared photo-acoustic gas analyzer (INNOVA 1412) and a multiplexer (1303). The configuration of the analyzer is given in table 2.

Table 2: Optical filters and detection limits of the photo acoustic infrared analyzer used in the experiment.

	Optical filter reference	*Detection limit (ppm)*
Ammonia	973	0.2
Carbon dioxide	982	1.5
Methane	969	0.4
Nitrous oxide	985	0.03

Strong interferences between ammonia and volatile fatty acids and alcohols emitted by maize silage distributed in the rooms were observed, mainly due to the configuration used for the gas analyzer. This caused large peaks of NH_3 concentration during feeding phases (Hassouna et al., 2012). Therefore, we decided to correct over-estimated ammonia emissions by suppressing these peaks. The subsequent NH_3 emissions are consequently potential ones. Finally, temperatures and humidity were continuously measured inside and outside the room.

2. RESULTS AND DISCUSSION: The deep litter in P1 was more humid (20.1% DM) than in P2 (27.2 %DM). This was also confirmed by the quantity of liquids produced by the FYM and collected, which were 471.65 kg in P1 and 267.05 kg in P2. This high moisture in P1 led us to remove the animals after only 4 weeks and explained the reason we did not have the same accumulation time for the two periods. For P1, emission values for weeks 5 and 6, and for P2, emission values for week 7 correspond to the litter alone as the cows were removed from the room (figures 1, 2, 3 and 4). Obviously, the litter emitted much more when cows were present than the litter alone. Without new input of elements from fresh manure, such as nitrogen or carbon, emissions of NH_3, CO_2 and CH_4 from the FYM rapidly decreased.

We observed more CH_4 emissions in P1 than in P2 (Table 3, Figure 3). This high level of CH_4 could be an indicator of anaerobic fermentation. As the liquid filled all the gaps in the litter (due to the high moisture), anaerobic conditions could occur. Moreover, no aerobic layer could have existed in P1 due to the moisture of the litter: oxidation of CH_4 into CO_2, which should occur in the top aerobic layer or during the rise of CH_4, was therefore prevented. CO_2 emissions, which were higher in P2 than in P1 (Table 3, Figure 1), validated these hypotheses. Regarding CH_4, as in Hansen et al.

(2002), we would also consider that the higher animal stocking density resulted in a higher emission of CH_4, because of both higher compaction of the litter and excretion by the animals.

High temperature in the litter was assumed because of (i) high fermentation and (ii) a mean temperature of the litter of 34°C at only 10 cm during P2 (we would expect a higher temperature in depth). The considerable moisture of the litter combined with the high temperature in the litter could explain the reason ammonia emissions were higher in P1 than in P2 (Table 3, Figure 4).

Finally, the full anaerobic conditions in P1 were validated by lower N_2O emissions in P1 compared with P2 (Table 3). As we could see a beginning increase of nitrous oxide emissions between weeks 3 and 5 in P2, we could imagine this was also the case between week 5 and 6 for P1 (Figure 2). Measurements at a longer time period would have confirmed this certainty. Anaerobic conditions in P1 seemed to slow down nitrification and therefore nitrous oxide formation.

Table 3: Mean emissions of GHG and ammonia according to the length of the period (measures with the litter alone are not included here).

	P1 (4 weeks)	*P2 (4 weeks)*	*P2 (6 weeks)*
CO_2-C (g/day/cow)	8214±0.46	8048 ±1.67	9003±1.61
N_20-N (g/day/cow)	0.433±0.213	0.468±0.157	0.909±0.504
CH_4-C (g/day/cow)	712.7±45.4	627.4±82.6	645.8±80.0
NH_3-N (g/day/cow)	97.2±13.9	56.0±11.63	60.2±11.8

In Figure 1 to 4, vertical bars indicate the standard deviation.

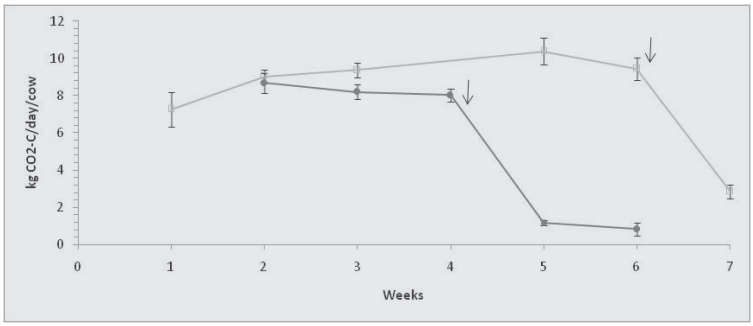

Figure 1. Mean CO_2-C emissions for P1 (•) and P2 (□); ↓ indicates when the cows left the room.

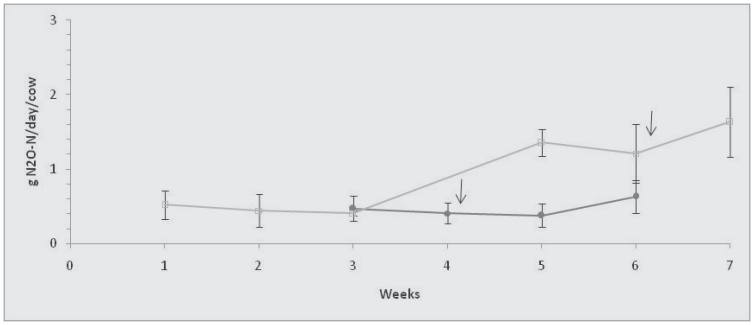

Figure 2. Mean N_2O-N emissions for P1 (•) and P2 (□); ↓ indicates when the cows left the room. (Values in week 2 are lacking).

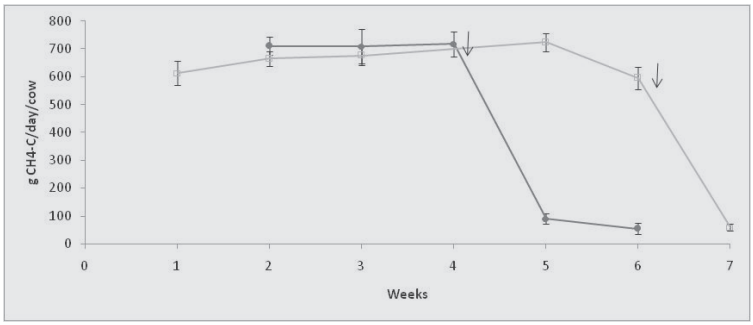

Figure 3. Mean CH_4-C emissions for P1 (•) and P2 (□); ↓ indicates when the cows left the room.

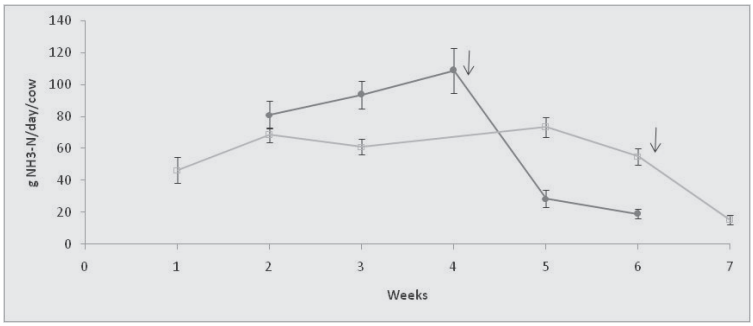

Figure 4. Mean NH_3-N emissions for P1 (•) and P2 (□); ↓ indicates when the cows left the room.

CONCLUSION: These results seem to indicate that inappropriate animal stocking density on a deep litter could lead to higher GHG and ammonia emissions. In this sense, both animal welfare and environmental issues recommend lower stocking densities for dairy cattle. These results improve our understanding of emitting processes related to deep litters.

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COMPARED EFFECTS OF DEHYDRATED LUCERNE AND SOYBEAN MEAL ON MILK PRODUCTION, DIGESTION, METHANE AND NITROGEN LOSSES IN DAIRY COW RECEIVING TWO FORAGES

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ABSTRACT: Dehydrated lucerne can be used in dairy cow rations as a protein source. The use of legumes is encouraged to mitigate greenhouse gas (GHG) emissions from agriculture; however little is known about effects of lucerne on GHG production by ruminants. Eight Holstein dairy cows weighing on average 582 kg were used in an experiment according to a replicated 4x4 Latin square design. They received diets based either on maize silage (M) or on grass silage (G) (45% of the diet), and the protein source was either soybean meal (S) or dehydrated lucerne (L) (15% or 30% of the diet, respectively). Diets MS, ML, GS, GL were calculated to meet energy and protein requirements for milk production and degradable-protein requirements for rumen microbes. Dry matter intake did not differ between diets (18.0 kg/d dry matter on average); milk yield was higher for S diets than for L diets (26.0 *vs* 24.1 kg/d on average, $P<0.001$) but did not vary with forage type. Methane production, measured by the SF_6 tracer method, was higher for G diets than for M diets, probably due to a higher fibre content, but did not differ with protein source (16.5, 15.7, 18.6 and 17.3 g/kg dry matter intake for MS, ML, GS, GL, respectively). The same effects were observed when methane was expressed per kg milk. Due to diet formulation constraints, N intake was higher for S than for L diets ($P<0.001$) with a significant interaction between forage type and protein source (418, 422, 475 and 396 g/d for MS, ML, GS, GL, respectively). The same statistical effects were shown for N in milk (122, 116, 127 and 109 g/d for MS, ML, GS, GL, respectively). Faecal and urinary N losses were determined from total faeces and urine collection. Faecal N was lower for M than for G diets ($P<0.001$) but did not differ between protein sources (148, 167, 193 and 185 g/d for MS, ML, GS, GL, respectively). On the contrary, urinary N did not differ with forage type but was lower for L than for S diets ($P>0.05$) (145, 111, 166 and 117 g/d, respectively; $P<0.001$). This suggests a decrease in ammonia emissions with L diets. In the conditions of this experiment, diets based on maize silage produced less methane than diets based on grass silage, whereas differences in N losses were minor. The substitution of soybean meal by dehydrated lucerne did not change methane production, but resulted in more N in faeces and less N in urine.

Keywords: dairy cow, dehydrated lucerne, soybean meal, grass silage, maize silage, methane, N losses

INTRODUCTION: Greenhouse gas (GHG) mitigation in ruminant farming can be achieved, among others, by changes in feeding. More than 60% of GHG emissions are due to animal end-products of digestion or metabolism: enteric methane and excreted nitrogen. Methane mitigation has been studied mainly by increasing the percentage of concentrates, by adding lipids or feed additives (Martin et al., 2010), but little attention has been paid to the nature of basal forage or protein sources. Nitrous oxide and other air or water pollutants such as ammonia and nitrates are related to N excretion through faeces and urine. Although the extent of pollution is mainly linked to manure management and application, changes in feeding may help reduce these components by decreasing excretion of total N or urinary N, which is in mineral form,

while faecal N is mainly in organic form (Eckard et al., 2010). The present experiment aimed to determine methane and N losses by dairy cows receiving two different forages and two different protein sources.

1. MATERIAL AND METHODS:

1.1. Experimental design, animals and feeding: Eight primiparous dairy Holstein cows weighing 582 kg were used after peak lactation in a double 4x4 Latin square design, during four 4-week periods. Measurements occurred during the last week. Animals received four diets differing in the nature of forage, either maize silage (M) or grass silage (G), and in the main protein source, either soybean meal (S) or dehydrated lucerne (L). All diets contained 45% M or G and either 15% S or 30% L, so that ca. 45% of dietary digestible protein was from S or L. The four experimental diets were defined by combining forage and protein source: MS, ML, GS, and GL. They were calculated to meet energy and protein requirements for milk production and degradable-protein requirements for rumen microbes. Animals were fed twice daily as a total mixed ration given in limited amounts just below the voluntary intake determined for each cow during the first 2 weeks of each period.

1.2. Measurements and analyses: Feed intake and milk yield were measured daily. Digestibility and N balance were determined by total faeces and urine collection for 6 days. In feeds, faeces and urine, organic matter (OM) was determined by ashing at 550°C for 6 h, and N was determined by the Kjeldahl procedure. Methane production was determined using the SF6 method according to Martin et al. (2008). Rumen liquid was sampled by rumenocentesis 2 h after morning feeding and volatile fatty acid (VFA) concentration was determined by gas liquid chromatography.

1.3. Statistical analyses: The statistical model was $Y=\mu+Fi+Nj+Pk+Al+FNij+e$, where Y is the dependent variable, μ is the mean, F is the type of forage, N is the protein source, P is the period, A is the animal, FN is the interaction between forage and protein source, and e is the error. Statistical analysis was performed using the MIXED procedure of SAS software. Forage, protein source and period were fixed effects, while animal was a random effect. Significance was declared at $P<0.05$.

2. RESULTS: Feed intake was similar among diets (Table 1). Milk yield was lower for L diets than for S diets, and the difference was more marked for G diets. Organic matter digestibility was higher for G diets than for M diets, and higher for S diets than for L diets. This corresponds to higher diet efficiency but also to lower undigestible OM. Despite differences in dietary N, faecal N did not differ among diets. Uninary N was lower for L diets than for S diets. Milk N followed differences in dietary N, and the ratio milk N/dietary N was relatively constant among diets. Enteric methane was lower for M diets than for G diets when expressed per day, per kg dry matter (DM) or per kg milk, but not as percentage of gross energy (GE) intake. Methane emission did not differ between S and L diets, regardless of the mode of expression. Ruminal VFAs, which are related to carbohydrate fermentation pathways, were not modified by diets, as shown by the absence of variation in the ratio (acetate + butyrate)/propionate, which is positively related to methanogenesis.

Table 1. Performances, digestion, methane production and N losses in cows fed diets differing in forage and protein source.

	Diet[†]				SE	Statistical effect[‡]		
	MS	ML	GS	GL		F	N	FN
Feed intake, kg DM/d	17.7	18.2	18.1	17.8	0.62	NS	NS	NS
Milk yield, kg/d	25.8	24.7	26.2	23.5	0.67	NS	0.01	0.02
OM digestibility (%)	73.7	66.8	75.9	70.2	0.01	0.01	0.01	NS
N intake	418	422	475	396	14.3	NS	0.001	<0.001
N in faeces	148	167	193	185	8.6	<0.001	NS	NS
N in urine	145	111	166	117	7.6	NS	<0.001	NS
N in milk	122	116	127	109	3.6	NS	<0.001	0.006
CH_4 (g/d)	310	307	366	332	17.2	0.02	NS	NS
CH_4 (g/kg DM intake)	17.8	17.0	20.1	18.7	0.98	0.05	NS	NS
CH_4 (% GE intake)	6.1	5.8	6.9	6.4	0.35	NS	NS	NS
CH_4 (g/kg milk)	12.2	12.4	14.1	14.1	0.63	0.01	NS	NS
(acetate + butyrate/ propionate)	4.31	3.86	4.41	4.26	0.176	NS	NS	NS

[†] MS : maize silage and soybean meal; ML : maize silage and dehydrated lucerne; GS : grass silage and soybean meal ; GL : grass silage and dehydrated lucerne

[‡] F : forage source ; N : protein source ; FN : interaction between forage source and protein source

DISCUSSION AND CONCLUSION: Previous research had shown that lucerne, given as forage, may reduce methane emission compared to grasses, perhaps due to its high content in malate or to a rapid rate of passage in the rumen. This study showed that dehydrated lucerne replacing soybean meal does not reduce methane. Malate content (1.3% of DM for L diets) was not enough to be efficient, and the use of lucerne in a dehydrated form probably did not change ruminal rate of passage. Methane was lower with M diets than with G diets, probably owing to a higher starch/fiber content.

Nitrogen excretion is generally related to N intake (Kebreab et al., 2001), but the replacement of soybean meal by dehydrated lucerne did not change feacal N output. It did, however, reduce urinary N output, so that the proportion of mineral N in excreted N decreased, which could help decrease N pollution. To date, however, the IPCC does not differentiate urinary and faecal N for calculations of emission of pollutants from manure. The lower undigestible OM with M and especially with L may contribute to a higher potential of methane production from manure.

This experiment showed the possibilities for mitigation of GHG emissions by dairy cows from animal feeding. However, a complete evaluation of emissions should be performed by methods such as life cycle assessment to account for indirect emissions arising, for example, from fertilisation for forages, the dehydration process for lucerne, or deforestation for soybean.

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VACUUM EVAPORATION TREATMENT OF DIGESTATE WITH USE OF HEAT FROM ANAEROBIC DIGESTION

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ABSTRACT: Within manure management strategies, anaerobic digestion followed by vacuum evaporation of digestate represents an interesting solution for both the reduction of nitrogen and phoshorous surpluses in soils and to avoid odour and gas emissions connected with the operations of treatment and storage of effluents. In reality, both anaerobic digestion and evaporation processes take place in a confined reactor, collecting gaseous emission as biogas and condensate, respectively. The aim of vacuum evaporation is i) to reduce the volume of the slurry to be spread on the field, thus reducing transport and distribution costs, and ii) to produce a condensate that can be discharged, to reduce the storage volume only to the concentrated fraction. Previous anaerobic digestion (AD) provides the heat necessary for the evaporation process, without it wasting in the atmosphere, as usually happens for the amount exceeding the needs of the digestor. With the goal to verify concentration efficiency, energy consumption and characteristics of concentrate and condensate, tests were performed using a one-stage semi-continuous pilot plant fed with the liquid fraction of a cattle slurry and maize silage digestate, without acidification. This practice is used to prevent ammonia volatilisation, but requires significant quantities of acid, thus increasing operational costs and causing problems for the on-farm storage of this product. A 12% TS concentrate was obtained, representing the 40-50% of the effluent. The condensate, because of its ammonia content (2.7 g/L on average) cannot be discharged. A solution for the recovery of ammonia from condensate is the filtration on reverse osmosis (RO) membranes, with previous acidification. Tests are on-going with a RO pilot plant to verify whether discharge limits can be matched. With a heat requirement of 0.87 kWh/kg of condensate, heat is the limiting factor of the process when the objective is to treat the entire quantity of digestate effluent from the biogas plant, especially in winter when the heat demand from AD plant increases.

Keywords: vacuum evaporation; anaerobic digestion, heat, emissions

INTRODUCTION: Vacuum evaporation enables the reduction of the volume of liquid waste through the evaporation and subsequent – apart - condensation of its water content. It is a process applied in different industrial and agroindustrial domains, currently on trial in the treatment of livestock effluents with the perspective to i) reduce the volume of the effluent to be spread on field, thus reducing transport and distribution costs, and ii) to produce a condensate that can be discharged to reduce the storage volume only to the concentrated fraction. Previous anaerobic digestion (AD) provides the heat necessary for the evaporation process, without it wasting in the atmosphere, as usually happens for the amount exceeding the needs of the digestor.

Heat recovery is important in improving energetic efficiency and environmental sustainability of biogas plants. In certain countries like France or Spain (and also Italy from 2013), the use of heat from the CHP unit for the treatment of digestate or other farm applications is a *conditio sine qua non* to have a right to bonuses in the feed-in tariff (Bonmati et al., 2003[2]).

With the goal to verify concentration efficiency, energy consumption, characteristics and uses of concentrate and condensate, tests were performed using a one-stage semi-continuous pilot plant fed with a cattle slurry and maize silage digestate.

1. MATERIAL AND METHODS: Eight tests of 6-8 hours each were performed, using a one-stage semi-continuous pilot plant. Inflow of digestate and outflow of condensate are continuous, while concentrate is discharged only at the end of the work. The pilot plant was installed close to a biogas plant of a 560 kWel and a 650 kWth power (580 kWth and 325 kWth residual after the quota for the digestor in summer and winter, respectively). The heat necessary for the evaporation process was provided by hot water coming from the CHP unit of the biogas plant.

The pilot plant was fed with the liquid fraction of the digestate after solid-liquid separation with a 0.5 mm screw-press. The influent flow rate was about 140 kg/h.

No previous acidification of the influent was used. This is a practice used to prevent ammonia volatilisation, but in the case of digestate it requires significant quantities of acid, thus increasing operational costs and causing problems for the on-farm storage of this product. Data from the Riducareflui Project show that 32 L/m^3 of a 35% sulphuric acid solution are required to reduce influent pH from 7.6 to 5, thus resulting in more than 99% of ammonia in the ionised, non-volatile form (Masse et al., 2008).

Samples of influent and concentrate were taken at the beginning and the end of each test, respectively, while samples of condensate were taken every 2 hours during the test. Total solids (TS, %p/p), ash (%p/p), total suspended solids (TSS, mg/kg), chemical oxygen demand (COD, mgO_2/L), total Kjeldhal nitrogen (TKN, mg/kg), ammonia ($mgN\text{-}NH_4/kg$) and total phosphorous (mgP/kg) were analysed following APAT-CNR-IRSA, 2003 standard methods.

Volumic reduction of the digestate was determined (1):

$$\text{vol reduction } \% = (\text{kg/h distillato} / \text{kg/h affluente}) * 100 \quad (1)$$

Nitrogen distribution between condensate and concentrate was determined as follows (2), kg/h Ni and kg/h Nc being nitrogen load in the influent and in the condensate, respectively.

$$\text{distribution } \% = (\text{kg/h } N_c / \text{kg/h } N_i) * 100 \quad (2)$$

Thermal consumption for the evaporation process was determined based on the average flow rate of the pump bringing hot water to the evaporator plant and on the temperature difference of the water before and after heat exchange (3):

$$p = Q * c_s * \Delta T \quad (3)$$

where: p = heat flow rate, kcal/h; Q = hot water flow rate, kg/h; s_h = water specific heat, kcal/(kg * °C); ΔT = difference in the temperature of water before and after the evaporation process, °C.

2. RESULTS AND DISCUSSION: Influent, condensate and concentrate characteristics are summarized in Table 1.

Starting from a digestate with a 4.2% TS, a concentrate with 11.9% TS was obtained, representing the 46% average of the influent flow (Table 2-A). In the condensate we find 46% of the total nitrogen (TKN) and 74% of the ammonia of the influent (Table 2-B). Average concentrations are 3.3 and 2.7 g/L, respectively, and the N-NH_4/TKN ratio is about 82%. Actually, ammonia seems to be the main chemical species characterising condensate, besides water.

The heat requirement for the evaporation process was calculated in 0.87 kWh/kg condensate produced. In this specific case, to treat the entire quantity of digestate produced daily by the AD plant (35 t/d), 763 kWhth were needed. Thus, the amount exceeding the needs of the digestor during the winter is insufficient.

Table 1. Composition of influent, concentrate and condensate (average, minimum and maximum values).

		TS (% p/p)	TSS (mg/kg)	VS (% p/p)	COD (mg/l)	TKN (mg/kg)	N-NH_4 (mg/kg)	NNH_4/TK N (%)	Ptot (mg/kg)	pH
influent	avg	4.24	30,886	3.00	41,150	3,058	1,766	58	676	7.8
	min	3.10	27,280	1.90	27,700	2,230	1,105	35	124	
	max	5.10	42,550	4.40	57,000	3,760	2,097	78	1,400	
concentrate	avg	11.88	-	7.79	-	4,687	1,138	24	1,902	8.9
	min	10.00	-	7.00	-	3,555	790	18	799	8.6
	max	14.20	-	9.10	-	5,900	1,317	28	2,640	9.1
condensate	avg				96	3,379	2,776	82	-	8.5
	min	nd	nd	nd	23	2,141	1,351	63	0	8.3
	max				318	5,148	4,440	96	122	8.8

Table 2. A. Average flow rate of influent, condensate and concentrate from evaporation tests. B. % distribution of TKN and N-NH_4 between condensate and concentrat (into brackets minimum and maximum values).

	A		B	
	flow rate		distribution %	
	kg/h	(%)	TKN	N-NH_4
influent	140 (123-156)	100	100	100
condensate	76 (64-84)	54 (50-60)	46 (32-59)	74 (56-81)
concentrate	64 (52-72)	46 (40-50)	54 (41-68)	26 (19-44)

CONCLUSION: Vacuum evaporation is an interesting process for the treatment of livestock effluents. The 40-50% reduction of the initial volume results in lower transport and land distribution costs; however, concentrate could be also sold as a fertilizer due to its high content in N, P and K.

Without previous acidification, condensate cannot be discharged due to its ammonia content. Nevertheless, matching discharge limits for condensate is an important target. The concentrate is the only fraction stored; also storage volumes (and thus costs) are reduced. A solution for the recovery of ammonia from condensate is the filtration on reverse osmosis (RO) membranes, with previous acidification. Products are permeate (to be discharged) and concentrate, a concentrated solution of ammonium salt (sulphate or phosphate, depending on the acid used) that could be mixed into the evaporation concentrate to increase its nitrogen content or sold as chemical fertilizer.

Many studies confirm the efficiency of RO filtration in the recovery of ammonium from a solution (ten Have et al., 1991; Masse et al., 2007, Masse et al., 2008). Tests are ongoing with a RO pilot plant to verify whether discharge limits can be matched, despite the costs of this post-treatment. Other possibilities may be cavitation (always with previous acidification) or microalgae cultivation.

Heat from AD can be a limiting factor when the target is to evaporate the whole daily digestate production. In this case, the amount that exceeds the needs of the digestor in winter (when heat demand from AD increases) is insufficient.

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THE FREQUENCY OF EMPTYING SLURRY ON GAS AND ODOURS EMITTED BY PIGGERIES EQUIPPED WITH FLUSHING SYSTEMS

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ABSTRACT: The main objective of this study was to determine the impact of the frequency of slurry flushing and its effects on ammonia and greenhouse gases emitted by swine buildings. This paper describes the results obtained from two fattening rooms equipped with flushing systems (rooms F2 and F4), compared to a reference room where slurry was stored during the entire fattening period. Slurry was removed twice a day in F2 and four times a day in F4. Pigs were individually weighed at the beginning, at feed change and on the day of slaughter. Feed and water consumption per room were recorded weekly. Temperature and hygrometry were continuously monitored inside and outside the three fattening rooms. The ventilation rate was continuously monitored by measuring the rotation speed of a full size free-running impeller unit, coupled with the exhaust fan in each room. Continuous measurements of ammonia and greenhouse gases were performed on exhaust air from the three rooms. Slurry samples were taken at the feed change and just after departure for slaughter. No significant effect of flushing frequency was observed on ammonia or greenhouse gases. Nevertheless, an increase in frequency led to a significant increase in odours emitted during the flushing process. The latter is of great concern in a country where the distance between pig units and urban areas is progressively being reduced.

Keywords: swine, ammonia, GHG, odour, flushing system

INTRODUCTION: In Europe, ammonia emissions for units with over 2 000 places for fattening pigs (+30 kg) or 750 places for sows are regulated by the Industrial Emission Directive (2010/75/UE). In the BREF document, a list of the Best Available Techniques (BAT) is given as effective ways to reduce ammonia emitted by piggeries. Among the techniques listed, frequent manure removal (flushing) is mainly illustrated, however, the efficiency of results show great variation. Previous studies have tried to determine the impacts of the recirculation liquid used and its efficiency. The main objective of our study was to determine the impact of the frequency of removing fresh slurry and its effect on ammonia, greenhouse gases and odours emitted from the swine buildings.

1. MATERIAL AND METHODS: Two successive batches of 144 crossbred (PPxLW)x(LWxLD) pigs were fattened at IFIP's experimental farm from April to December 2010 in three housing conditions, which differed only in slurry management. In the first room (reference), slurry was stored underneath in a pit during the entire fattening period. In the two remaining rooms (F2 and F4), slurry was removed twice (10 am and 10 pm) and four times (4 am, 10 am, 4 pm and 10 pm) per day, respectively. In F2 and F4, the recirculation liquid was the liquid fraction of the slurry produced by pigs kept in each room. The liquid fraction was obtained by decantation of the slurry. For the three rooms, 48 pigs were group-housed in 6 pens on fully slatted floors. The total pen area per animal was 0.7 m^2. Fresh air entered via a ceiling of perforated plastic sheeting, and air exhaust was under-floor extraction via a chimney. Pigs were individually weighed at the beginning of the growing period, and thereafter, every three weeks and the day before slaughtering. Feed intake was

recorded weekly on a pen basis. Water consumption was recorded daily on a pen basis. At slaughter, carcase characteristics were individually recorded. Temperature and hygrometry were continuously monitored inside and outside the three fattening rooms. The ventilation rate was continuously monitored by measuring the rotation speed of a full-size free-running impeller unit, coupled with the exhaust fan of each room. The set-point temperature was fixed at 24°C during the entire period. For the three rooms, gas concentrations (NH_3, N_2O, CH_4, CO_2 and water vapour) were measured inside and outside with a photoacoustic Multi-gas Monitor 1412 (Innova Air Tech Instrument), coupled with a sampler dosimeter 1303 (Innova Air Tech Instrument). Emission factors were validated by the mass-balance method. The mass-balance method was applied for nitrogen (N), carbon (C) and water (H_2O) including the calculation of inputs (piglets, feed consumption) and ouputs (pigs, slurry composition, gaseous emissions). Slurry samples were taken in the pit six times during the fattening period. Dry Matter, pH, total nitrogen, ammonium nitrogen and total carbon were analysed from each sample. Air samples for odour measurements were achieved in accordance with the European CEN standard, using dynamic olfactometry and analysed to determine the odour concentration. An analysis of variance (SAS 1998, proc GLM) was performed to test the effects of sex (X) and treatment (T) on animal performance.

2. RESULTS AND DISCUSSION:

2.1. Growth performance: For both rooms, the fattening duration was 86 days as all pigs were slaughtered on the same day. The slaughtering weight was 110.7±5.3, 109.5±5.0 and 112.2±4.3 kg for B1 and 117.0±3.0, 115.5±5.0 and 115.8±5.0 kg for B2, respectively for pigs kept in Reference, F2 and F4 rooms. In B1 (Reference, F2 and F4), ADG was 809.7±73.5, 785±72.6 and 828.0±71.7 $g.d^{-1}$ in B1 and 876.0±45.6, 841.2±68.9 and 859.9±79.8 $g.d^{-1}$ in B2 (Reference, F2 and F4). In B1 (Reference, F2 and F4), FCR was 3.15±0.26, 2.82±1.16 and 2.79±0.16 $kg.kg^{-1}$ and 2.95±0.14, 3.08±0.27 and 3.13±0.31 $kg.kg^{-1}$ in B2 (Reference, F2 and F4).

For B1, the growth performance (ADG and FCR) of pigs kept in F4 was significantly higher ($Pr<0.01$) than the performance of pigs kept in the Reference and F2 rooms. For B2, no significant effect of the treatment was observed on animal performance.

2.2. Ambient parameters: Table 1 lists temperature and ventilation rates recorded during the fattening of two successive batches. The differences observed between both batches are due to variations in weather conditions. Per batch, no significant difference was observed between the three rooms involved in this study.

2.3. Input-Output mass balances: For nitrogen the mass-balance deficit per room was 0.5, 0.6 and 1.2% of the input of nitrogen for B1 and 2.5, 0.7 and 0.5% for B2, respectively for Reference, F2 and F4. For carbon, the mass-balance deficit per room was 14.7, 5.1 and 3.6% of the input of carbon for B1 and 12.3, 7.2 and 7.1% of the input of carbon for B2, respectively for Reference, F2 and F4.

Table 1. Ambient parameters.

	Reference	F2	F4	Outside
Temperature (°C)				
B1 (April to July)	27.4±3.7	27.8±3.6	28.7±4.4	16.9±7.4
B2 (Sept. to Dec.)	25.3±2.0	25.0±2.1	24.6±2.2	10.8±6.3
Air flow rate ($m^3.h^{-1}.p^{-1}$)				
B1 (April to July)	31.3±13.6	31.4±13.0	31.2±12.9	-
B2 (Sept. to Dec.)	31.2±11.9	29.3±11.8	29.5±11.6	-

2.4. Gaseous emissions: Nitrogen emissions (NH_3 and N_2O) measured for the Reference, F2 and F4 rooms accounted for more than 80% of the nitrogen loss by volatilization, calculated by the input-output mass balances for both batches. For B1, ammonia emissions were 3.0, 3.4 and 3.6 g N-NH_3 per pig per day in the Reference, F2 and F4 rooms, respectively. For B2, ammonia emissions were 3.8, 4.9 and 3.9 g N-NH_3 per pig per day in the Reference, F2 and F4 rooms, respectively. The N_2O emissions were 0.5, 0.5 and 0.1 g N-N_2O per pig per day for B1 and 0.5, 0.7 and 0.5 g N-N_2O per pig per day for B2 for Reference, F2 and F4 rooms, respectively.

Values of ammonia emissions obtained for the Reference room were lower than values published in the literature (Philippe et al., 2007) but were in accordance with values obtained in our previous studies (Guingand et al., 2011). Concerning N_2O emissions, values measured in the Reference room were in accordance with data published by Philippe et al., (2007). For B1, ammonia emissions increased 20% when slurry was removed four times per day compared with only 12% when slurry was removed twice a day. Those results were not confirmed with data obtained in B2. For both batches, no positive effect of the slurry removal was observed on ammonia emissions.

For both batches, carbon emissions (CO_2 and CH_4) measured during the entire fattening period represented 75-90% of the carbon lost through volatilization, calculated by the input-output mass balances. For CH_4, emissions were 9.1, 6.8 and 5.9 g C-CH_4 per pig per day in B1 and 5.8, 3.1 and 3.1 g C-CH_4 per pig per day in B2 for the Reference, F2 and F4 rooms, respectively. For CO_2, emissions were 496.3, 482.6 and 431.8 g C-CO_2 per pig per day in B1 and 588.6, 581.2 and 562.6 g C-CO_2 per pig per day in B2 for the Reference, F2 and F4 rooms, respectively.

Values of methane measured in the Reference room were close to literature values. According to Gallman et al. (2003), CH_4 emissions ranged between 6 and 9 g C_CH_4 per pig per day. In our study, CH_4 emissions were reduced by 25% for F2 and 35% for F4 in B1, and the reduction was close to 45% for F2 and F4 in B2.

2.5. Odours: For the Reference room, the average odour emission was 4.2 10^5±3.3 10^5, 5.0 10^5±3.8 10^5 and 3.8 10^5±2.9 10^5 odour units per pig per day (B1) and 6.7 10^5±4.0 10^5, 2.5 10^6±2.0 10^6 and 1.5 10^6±1.2 10^5 odour units per pig per day (B2), for the Reference, F2 and F4 rooms, respectively. For B1, increasing flushing frequency to four times per day induced only a 10%decrease in odour emissions compared to the Reference room. However, removing slurry twice a day induced an increase of 17% in odour emissions. For B2, an increase in slurry removal led to a greater increase in odours emitted from F2 and F4.

Limiting the duration that slurry stays inside the swine buildings is commonly accepted as a way of reducing gaseous emissions and odours (Belzile et al., 2006). Nevertheless, in our study, the slurry agitation induced by flushing seems to be the main factor in additional emissions of ammonia and odours. This negative effect was described by Hoff et al. (2006), who observed a dramatic increase in NH_3, H2S and odours during slurry-removal events. The increase in the exchange surface between fresh slurry and ambient air explains the rise in gaseous compounds emitted during slurry removal. Volatilization is thus increased with higher removal frequencies.

CONCLUSION: The aim of this study was to compare the incidence of two different frequencies of slurry removal on animal performance, gaseous emissions and odors. In our study, removal frequency did not have a significant effect on ammonia and GHG emissions. Nevertheless, the increase in the frequency led to a significant rise in odours emitted during the flushing process. The latter is of great concern in a country where the distance between pig units and urban areas is progressively being reduced.

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MEASUREMENT OF AMMONIA EMISSION FROM NATURALLY VENTILATED DAIRY HOUSES

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ABSTRACT: Emission of ammonia (NH_3) from dairy production is a significant source in the national emission inventory of polluting gases. New NH_3 abatement technologies suited for dairy houses are therefore needed. However, to develop and evaluate in-house technologies and to establish emission models for dairy production, reliable measuring systems are required. A study was therefore carried out to develop an NH measuring system and to quantify NH_3 emissions of naturally ventilated dairy houses equipped with different manure handling systems. The study was carried out at five commercial dairy farms and included two different manure-handling systems. Gas concentrations inside and outside each dairy house were continuously measured in three measuring periods of two weeks distributed over a meteorological year. Gas concentrations were quantified with a photo-acoustic multigas monitor. NH_3 emission was calculated by measured gas concentrations and calculated air exchange in the buildings, estimated using a tracer-gas dilution model based on the CO_2 production of the housed dairy cows. The mean daily NH_3 emission per dairy cow housed in a cubicle housing system with a slatted floor varied from 20-56 g NH_3-N cow^{-1} day^{-1}. On average, daily ammonia emission was 37 g NH_3-N cow^{-1} when only the slatted floor was scraped and 30 g NH_3-N cow^{-1} when both the slatted floor and manure culverts were scraped.

Keywords: ammonia emission, dairy production, manure handling, measuring systems

INTRODUCTION: Emission of ammonia (NH_3) from livestock production reduces the nutrient value of livestock slurry and has detrimental effects on ammonia-vulnerable habitats. National and international environmental authorities have therefore introduced stricter regulation to reduce emissions from animal houses and manure storage systems. The Danish environmental authority requests that ammonia emission from future dairy production be reduced by at least 43% per cow when dairy cows are housed in cubicle housing systems with slatted floor and a recirculating manure channel system. This increases demands for development and documentation of new environmental technologies. As livestock manure is the major source of ammonia emission in dairy production, the main focus is its reduction.

To document the environmental effects of ammonia-abatement technologies suited for dairy production, a reliable measuring system suited for naturally ventilated housing systems is required. A study was therefore carried out to develop an NH_3 measuring system and to quantify NH_3 emission for naturally ventilated dairy houses equipped with different manure-handling systems.

1. MATERIAL AND METHODS: An ammonia-emission measuring system suited for measurement in naturally ventilated animal houses was developed and evaluated. It was based on continuous on-line measurement of ammonia concentrations in in-house and outdoor air and simultaneous calculation of in-house air exchange by a tracer-gas method. The tracer gas used in the study was the CO_2 produced from respiration by the housed cattle. Air exchange (V) was calculated as:

$$V = \frac{10^6 \cdot E_s}{\rho_s(t)(C_{st} - C_{su})}$$

where V is air exchange in $m^3\ h^{-1}$, E_s is tracer-gas emission in kg h^{-1}, $\rho_s(t)$ is the density of tracer gas in kg m^{-3} air at a given temperature t, and C_{si} og C_{su} are the measured concentrations of tracer gas in mg m^{-3} of in-house and outdoor air. Cattle CO_2 emission was estimated as 0.185 m^3 HPU^{-1} (Heat Production Unit, CIGR, 2002; Zhang, 2005). HPU was calculated based on the actual age, weight and milk production per housed animal at the start of the observation period (CIGR, 2002).

The emission E_g of a given gas (g) was calculated as:

$$E_g = V\rho_g(t)(C_{gi} - C_{gu})$$

$$E_g = E_s \frac{\rho_g(t)(C_{gi} - C_{gu})}{\rho_s(t)(C_{si} - C_{su})}$$

where C_{gi} og C_{gu} are the measured concentrations of ammonia in mg m^{-3} air in in-house and outdoor air.

Table 1. Sampling periods, numbers of cattle, and mean in-house temperatures for the test farms studied.

Test farm	1			2			3			4			5		
Technology	Scraping of slatted floor			Scraping of slatted floor			Scraping of slatted floor			Scraping of slatted floor and slurry channels			Scraping of slatted floor and slurry channels		
Test period	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Start of sampling	01.06	21.07	17.01	15.09	04.05	06.07	24.08	16.04	23.06	19.11	29.11	06.01	18.10	02.12	20.06
End of sampling	16.06	12.08	23.01	29.09	27.05	21.07	31.08	30.04	05.07	27.11	20.12	17.01	08.11	22.12	14.07
Number of dairy cows	152	152	145	212	221	206	126	115	121	135	125	126	128	125	129
Number of heifers	10	10	5	0	0	0	0	0	0	16	14	17	20	23	14
In-house temperature	15.2	17.8	4.2	14.8	13.1	21.2	17.6	11.0	20.8	3.9	1.2	4.8	8.4	-1.2	17.6

To evaluate the measuring method and quantify the ammonia-abatement effect of manure-handling systems, ammonia emission of five commercial dairy productions using two different manure-handling systems was studied (Table 1). Two of the dairy houses were equipped with a mechanical manure-removal system in slurry ducts, while the other three houses were equipped with a recirculation manure-channel system. All dairy houses were equipped with automatic systems for frequent scraping of the slatted floors to reduce ammonia emission and hoof problems (Figure).


Figure 1. Two methods for scraping slatted floors in dairy houses: a robotic scraper (left) and a wire-propelled scraper (right).

All dairy houses were naturally ventilated with large side wall and ridge openings. Gas concentrations inside and outside each dairy house were continuously measured in three measuring periods of two weeks. The periods occurred at different times of year to include a variety of climatic conditions. Gas concentrations were quantified with a photo-acoustic multigas monitor (INNOVA, 1312, Copenhagen, Denmark).

2. RESULTS AND DISCUSSION: Mean daily NH_3 emission per dairy cow housed in a cubicle housing system with a concrete slatted floor varied from 20-56 g NH_3-N cow^{-1} day-1. On average, daily ammonia emission was 37 g NH_3-N when only the slatted floor was scraped and 30 g NH_3-N when both the slatted floor and manure culverts were scraped (Table 2).

Emissions were influenced by a number of factors, such as in-house temperature, wind speed, manure management, and air humidity. On average, emissions were at or slightly above the national emission factors for cattle held in housing systems with a slatted floor above slurry channels (Poulsen, 2011). This indicates that the abatement effect of scraping slatted floor and slurry channels is either lower than expected or that the national ammonia emission factors for cattle slurry are higher than previously estimated.

Table 2. Mean NH_3 emission in relation to the calculated excretion of total nitrogen (N) and Total Ammoniacal Nitrogen (TAN) from dairy cows housed in naturally ventilated dairy houses. The dairy houses were equipped with two different NH_3-abatement manure-handling systems. Values in parenthesis are standard deviations.

Type of floor		Slatted floor	Slatted floor
Manure handling technology	Unit	Floor scraper	Floor and channel scraper
Estimated N excretion	g N cow^{-1} d^{-1}	432 (26.4)	397 (14.6)
Mean NH_3-N emission	g N cow^{-1} d^{-1}	37.4 (12.3)	30.0 (6.9)
Relative NH_3 emission loss	% of excreted N	8.7 (3.1)	7.6 (1.7)
Relative NH_3 emission loss	% of excreted TAN	18.3 (6.9)	15.9 (4.4)

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EFFECT OF CARBOHYDRATE SOURCE AND RUMEN PH ON ENTERIC METHANE FROM DAIRY COWS

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ABSTRACT: The aim of this experiment was to measure the enteric methane emissions in dairy cows fed diets rich in starch or sugar with and without manipulation of rumen pH. The rations were based on grass-clover silage supplemented with either wheat (W), NaOH treated wheat (WNaOH), sugar beet molasses (M) or sugar beet molasses with sodium bicarbonate (MBic). Wheat or molasses made up 35% of the ration dry matter (DM). Four cows were used in a 4 x 4 Latin square design. Emissions of methane and hydrogen were measured by means of open circuit indirect calorimetry on four consecutive days. The cows produced 32.1, 33.0, 35.9 and 34.7 l CH_4 per kg DM on diet W, WNaOH, M, and Mbic, respectively. The emission of CH_4 per kg DM ($P=0.03$), and the daily hydrogen emission ($P<0.001$) were higher on molasses diets compared to the wheat diets. It is concluded that methane emission is higher in sugar-rich than in starch- rich diets.

Keywords: CH_4, dairy cows, wheat, molasses, mitigation strategy

INTRODUCTION: Methane is a greenhouse gas which contributes significantly to the carbon footprint of ruminant products e.g. milk and meat. Starch and sugar are both highly degradable in the rumen, but they affect rumen fermentation differently and thereby also the enteric methane production. Starch directs the fermentation pattern towards propionate, which acts as a hydrogen sink, whereas sugar directs the fermentation pattern towards butyrate, resulting in a net production of hydrogen. Rumen pH affects the fermentation pattern as a decrease in pH favors propionate production, and thereby reduces hydrogen available for methane production (Murphy et al., 1982). The aim of this experiment was to test the effect of starch versus sugar and manipulation of rumen pH on enteric methane production.

1. MATERIAL AND METHODS: Four cows (3 primiparous and 1 multiparous) were used in a 4 x 4 Latin square design. The cows were 197 days in milk (sd 158) and had an average milk yield of 21.4 kg (sd 6.1 kg). All four diets were based on grass-clover silage and soya bean meal. Treatments were 2x2 factorials with the carbohydrate source (wheat vs. molasses) and pH (untreated vs. NaOH (wheat) or buffer supplementation (molasses)) as factors. For all diets, the supplement made up 35% of the dry matter (DM), and was either ground wheat (W), NaOH treated wheat (WNaOH), sugar beet molasses (M) or sugar beet molasses with sodium bicarbonate (MBic) (Table 1). Feed was prepared once daily as total mixed rations before the morning feeding and fed ad libitum. Cows were milked and fed twice daily at 6:00 and 17:00. All periods consisted of four weeks. Digestibility and rumen pH were measured in the third week in each period. The digestibility data are not reported here. In the fourth week methane and hydrogen emissions were measured on four consecutive days by means of open-circuit indirect calorimetry. Calculated methane emissions are given at standard temperature and pressure (0 °C (273.15 K) and 101.325 kPa). Daily DM intake was measured as the difference in DM fed and DM in left-overs. Milk yield was recorded daily and milk composition was determined once weekly. Energy corrected milk (ECM) was calculated according to Sjaunja et al. (1991). Feed samples of diets and ingredients were taken once weekly and analyzed

for DM, ash, fat, starch, sugar and NDF. Data was analyzed with PROC MIXED in SAS with carbohydrate source, pH, period, and interaction between carbohydrate and pH as fixed effects and cow as random. Results are presented as least square means (LSmeans) and the root means square error (RMSE) is given for each variable. Pairwise comparisons of LSmeans were made by use of the PDIFF option, and effects were considered significant when $P<0.05$.

Table 1: Dietary and chemical composition of four diets.

	W	WNaOH	M	MBic
Composition of rations (g/kg DM)				
Grass-clover silage	494	490	494	490
Wheat	353			
NaOH treated wheat		359		
Sugar beet molasses			353	350
$NaHCO_3$				9.3
Soy bean meal	141	140	141	140
Minerals and vitamins	12	12	12	12
Chemical composition (g/kg DM)				
Ash	60.6	74.6	97.5	103
Protein[1]	172	171	177	175
Fat	25.8	24.4	16.5	16.7
Starch	243	257	7.6	3.8
Sugar	34.2	30.0	241	238
NDF	318	290	280	277
Energy concentration (MJ/kg DM)				
Gross energy[2]	18.8	18.5	18.0	17.9

W: Diet with ground wheat, WNaOH: Diet with NaOH treated wheat, M: diet with molasses, MBic: Diet with molasses and bicarbonate.

[1] Feed table values

[2] Calculated according to Volden and Nielsen (2011)

2. RESULTS AND DISCUSSION: Neither DM intake nor gross energy intake (GEI) were significantly different between treatments. However, DMI was approximately 1.5 kg lower on diet W than the other diets (Table 2).

Milk production in ECM was affected by diet ($P=0.03$), and cows fed WNaOH had the highest production. Although the ECM production on W was in the same range as the two molasses diets, there was a significant effect of carbohydrate source on ECM production. The lower ECM production on W was probably due to the lower DM intake.

Cows produced 32.1, 33.0, 35.9 and 34.7 L CH_4 per kg DM on diet W, WNaOH, M, and Mbic, respectively. The methane production on the two molasses diets was significantly higher ($P=0.03$) than on the two wheat diets. This fits with data from Hindrichsen and Kreuzer (2009), who found higher methane production from sugar than from starch in an in vitro system. However, an in vivo experiment with dairy cows fed a diet with molasses did not result in more enteric methane than cows fed a diet with wheat (Hindrichsen et al., 2005). The missing effects in the experiment by Hindrichsen et al. (2005) could be due to differences in diet composition; the sugar level was only 60% of the M and MBic level and the starch level was comparable with the starch level in the W and WNaOH diets. Müller et al. (1994) did not find differences in total daily enteric methane emissions with sugar beet, but CH_4 per kg DM was higher on diets with sugar beet than without. This supports the hypothesis that starch and sugar affect rumen fermentation differently (Murphy et al., 1982). There was no effect on methane production of the NaOH treatment of wheat or supplementing molasses with sodium bicarbonate. The measured pH in the ventral rumen was similar on all diets (Table 2) and may explain the lack of effect on methane emissions.

Table 2. Feed intake, methane and hydrogen production, and rumen pH.

	Diet					P-values		
	W	WNaOH	M	MBic	RMSE	Carbohydrate	pH	interaction
DMI [kg/d]	16.9	18.4	18.5	18.2	1.18	0.25	0.33	0.17
GEI [MJ/d]	319	344	336	328	21.9	0.94	0.48	0.19
ECM [kg/d]	22.9	26.5	22.3	21.6	1.72	0.02	0.14	0.05
CH_4 [L/day]	532	593	642	608	46.3	0.04	0.58	0.09
CH_4 [L/DMI]	32.1	33.0	35.9	34.7	1.93	0.03	0.88	0.33
CH_4 [L/ECM]	23.6	23.2	28.9	28.4	1.42	<0.001	0.52	0.93
CH_4 /GE [%]	6.6	6.8	7.5	7.3	0.34	0.005	0.95	0.23
H_2 [l]	5.6	4.7	28.0	27.5	5.1	<0.001	0.77	0.91
pH	6.40	6.45	6.41	6.45	0.16	0.96	0.56	0.96

W: Diet with crushed wheat, WNaOH: Diet with NaOH treated wheat, M: diet with molasses, MBic: Diet with molasses and bicarbonate, DMI: Dry matter intake, GEI: Gross energy intake, ECM: Energy corrected milk, RMSE: Residual error.

The loss of gross energy as methane was 7.4% for the two molasses diets, which was significantly more (P=0.005) than the 6.7% on the two wheat diets. The level for the two molasses diets was comparable with the levels found by Müller et al. (1994) for sugar beet.

On average, 28 L H_2 escaped the rumen on the two molasses diets, whereas only 5 L H_2 was emitted on the two wheat diets. Peak emission of hydrogen was observed just after feeding. Hindrichsen and Kreuzer (2005) did not find differences in emitted hydrogen between sugar and starch in an in vitro experiment. Pinares-Patiño et al. (2011) found higher emissions of hydrogen when sheep were fed concentrate instead of grass, indicating that hydrogen production in some situations may exceed the utilization capacity of the rumen methanogens.

CONCLUSION: In conclusion, diets rich in sugar beet molasses caused higher emissions of both methane and hydrogen than diets rich wheat.

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COSTS OF AMMONIA EMISSION ABATEMENT IN LIVESTOCK FARMING

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ABSTRACT: A wide range of measures for reducing ammonia emissions is available for livestock farming that largely differ in their suitability and effectiveness as well as related costs. Mitigation costs for selected technological and organizational abatement measures in pig feeding and housing, as well as storage and incorporation of pig and cattle manure were calculated. In pig fattening, strong reductions in N excretions and ammonia emission rates can be achieved by crude-protein-adapted phase-feeding systems. Higher investment costs and costs for amino-acid supplementation are compensated by saving expensive protein components. Air purification systems are technically efficient, yet cost-intensive, abatement measures. Also, naturally free-ventilated houses, as an alternative to closed houses with forced ventilation cause high mitigation costs. Both techniques, however, serve other goals besides ammonia reduction, a fact that has to be considered in the calculations. Slurry storage covers, particularly for pig slurry, are highly cost-effective abatement measures. The same applies to the incorporation of slurry and the use of trailing shoes, slot injectors or direct incorporation by a cultivator. Yet, all abatement measures lose effectiveness if no further measures are applied in downstream farming operations. Through a combination of measures the highest emission reduction can be realized.

Keywords: NH_3, housing, storage, application, abatement costs

INTRODUCTION: Ammonia (NH_3) emissions contribute to the acidification and eutrophication of ecosystems and have an indirect effect on the climate. Livestock farming is the most prominent source of NH_3. To mitigate the environmental damage and to comply with internationally agreed NH_3 emission ceilings, reducing emissions from livestock farming is essential. A wide range of measures for reducing NH_3 emissions is available for livestock farming, including measures for housing and the storage and incorporation of manures. These measures, however, largely differ in their suitability and effectiveness as well as related costs. The KTBL project "Systematic cost-benefit analysis of reduction measures for ammonia emissions in agriculture for national cost estimates" therefore aimed to calculate mitigation costs for selected technological and organizational abatement measures suitable for Germany in feeding, housing, storage and application of manure. Further, the influence of downstream farming operations on the effectiveness of measures taken in upstream operations was evaluated for selected combinations of measures.

1. MATERIAL AND METHODS: For the calculation of NH_3 abatement costs, the farming activities of feeding and housing of pigs and storage and application of cattle and pig manure were considered. For each farming activity, selected abatement measures were defined based on the UN/ECE guidance document, appendix IX of the Gothenborg Protocol and the BREF reference document "Intensive Rearing of Poultry and Pigs" (European Commission, 2003) (Table 1).

Table 1. Selected abatement measures for ammonia emissions in agriculture.

Activity	Reference	Abatement measure	Species	Reduction %
Feeding	Single phase	Two, three and multiple phase, crude protein adapted diet	Pigs	10-30
Housing	Forced ventilation, fully slatted floor	Natural ventilation	Pigs	35
	No exhaust air purification	Exhaust air purification	Pigs	70–90
Storage	No cover	Natural floating layer	Pigs	20–70
			Cattle	30–80
		Chopped straw	Pigs/cattle	70-90
		Granules	Pigs/cattle	80–90
		Floating sheets	Pigs/cattle	80–90
		Floating tiles	Pigs	> 90
		Solid cover	Pigs/cattle	85–95
Application	Broadcast spreader	Trailing hose	Pigs/cattle	30/20
		Trailing shoe	Pigs/cattle	50/40
		Open slot injection	Pigs/cattle	60
		Cultivator	Pigs/cattle	90
		Incorporation within 1 h	Pigs/cattle	90
		Incorporation within 4 h	Pigs/cattle	70/50

Source: Döhler et al., 2002; Döhler et al., 2011; Eurich-Menden et al., 2011

1.1. Calculation of emission abatement: Abatement of NH_3 emissions is calculated as the difference between the emission without the abatement measure (reference) and the emission with the abatement measure. For the references, emission factors from the national emission report are used (Haenel et al., 2010) or derived from literature. The emission abatement is either indicated as a percentage or as a separate emission factor related to the reference emission. Depending on the farming activity, the emissions are indicated per animal head (feeding), per animal place (AP) (housing) or per volume or weight of manure (storage and application) (European Commission, 2003).

1.2. Calculation of abatement costs: To calculate abatement costs, all additional costs related to the abatement measure are considered. These include fixed and variable costs, but also benefits (e.g. saved fertilizer) or indirect costs (e.g. additional water in the manure storage). Since the costs of abatement measures result from the difference between costs with and without the abatement measure, the costs for the reference also have to be considered. If abatement measures serve other goals besides NH_3 emission abatement, costs and benefits have to be allocated to all goals. Costs are specified per unit of NH_3 emission abatement.

2. RESULTS AND DISCUSSION:

2.1. Feeding: Fixed costs of multi-phase feeding systems are 27-52% higher than those of single-phase feeding systems, depending on the number of animal places and the feeding system. However, variable costs, notably feed costs, are 10-13% lower, because cost-intensive protein-rich feed is saved. This compensates the increase in fixed costs, and total annual costs are thus lower in multi-phase feeding compared to single-phase feeding. NH_3 emissions decrease most clearly (by 32%) when applying two-phase feeding instead of single-phase feeding, while a further increase in the number of phases only has a small additional effect. Hence, a two phase feeding system tends to be the most cost-effective abatement measure. The cost saving along with the reduction of NH_3 emissions result in negative abatement costs.

2.2. Housing: Pig fattening in naturally free-ventilated houses leads to 28% higher investment costs and thus higher fixed costs than in houses with forced ventilation. In addition, more labor is required. However, the higher labor costs are compensated by lower energy costs for ventilation and heating; as a consequence total variable costs for the two housing systems are equal. For houses with 960 animal places, NH_3 abatement costs of 9.20 €/kg NH_3 are obtained. The main reason for free-ventilated houses is increased animal welfare. If 80% of the costs are allocated to this aim, NH_3 abatement costs are 1.84 €/kg NH_3.

2.3. Exhaust air purification: Exhaust air purification systems are a cost-intensive abatement measure with total annual costs amounting to 15-28 €/(AP • yr), depending on the number of animal places and system type. With 10-year depreciation, 50% of annual costs relate to fixed costs, a further 25-30% result from higher energy requirements, while labor costs only amount to 10%. Calculated abatement costs range between 4.60 €/kg NH_3 for large farms (2,000 AP) with three-stage air purification and 8.60 €/ kg NH_3 for smaller farms (500 AP).

2.4. Manure storage: Lightweight expanded clay aggregate (LECA) covers are the most cost-effective NH_3 abatement measure, high investment costs being compensated by high durability and low maintenance and repair costs. Thus, annual costs of a LECA cover for a 500 m³ tank are 2.00 €/(m³ slurry • yr). Tents and floating sheets were cost-effective abatement measures for 5,000 m³ tanks, with annual costs of 1.75 €/(m³ slurry • yr) and 1.50 €/(m³ slurry • yr), respectively. Straw is an inexpensive, easily available cover type, but whose costs, however, increase significantly if it must be replaced frequently. As a result of a lower reference emission due to a natural crust, the reduction potential of measures for cattle slurry are lower, leading to higher abatement costs compared to pig slurry. For example, abatement costs of LECA covers are 1.75 €/kg NH_3 for cattle slurry and 0.35 €/kg NH_3 for pig slurry for a 500 m³ tank.

2.4. Manure application: Abatement costs of measures for manure application are 11-20% lower for cattle slurry than those for pig slurry. This is due to a higher reference emission of cattle slurry caused by slower infiltration into the soil, resulting in a higher abatement potential of measures. The immediate incorporation of slurry with a separate tractor results in abatement costs of less than 1 €/kg NH_3, independent of the slurry amount applied annually. Lower costs can be achieved only with slurry cultivators or injectors if large amounts of slurry are applied annually.

2.5. Combination of measures: While immediate incorporation is an efficient and cost-effective individual abatement measure, covering the tank or exhaust-air purification have a lower efficiency if applied without any further measures in downstream farming activities. If emissions are reduced in housing, more NH_3 reaches the slurry tank, increasing the emissions there. Consequently, part of the mitigation effect in animal housing is lost. At the same time, however, the reduction measure in the tank becomes more cost-effective. Through a combination of measures for emission abatement in different farming activities, maximum emission abatement is achieved (Figure 1).

Abatement costs, €/kg NH_3	1.03	0.76	0.75	3.46	8.46
Additional costs, €/(AP • yr)	0.77	2.00	1.23	19.91	17.91
Abatement, %	11	38	24	84	31

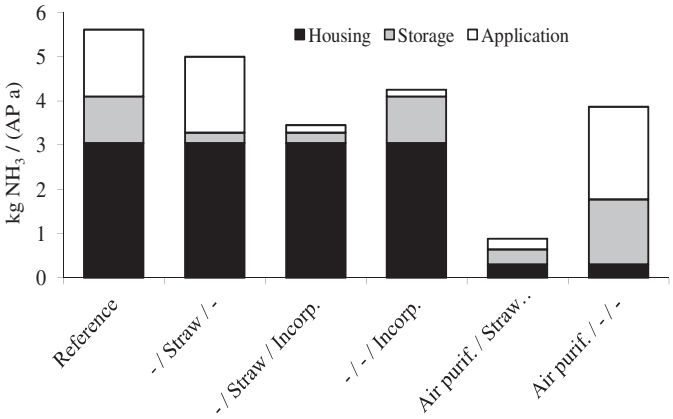

Figure 1. NH_3 emission abatement of selected combinations of measures in pig fattening (Reference: housing with forced ventilation, 1,000 animal places, uncovered 1,000 m³ tank, broadcast application without incorporation).

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COMBINATION EFFECT OF CLOVE AND ORANGE PEEL OILS ON RUMEN GAS AND METHANE PRODUCTION USING IN VITRO GAS PRODUCTION TECHNIQUE

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ABSTRACT: Clove and orange peel oils were used for rumen manipulation in ruminant animal production. The objective of this study was to evaluate the combination effect of clove and orange peel oils on rumen gas and methane production by an in vitro gas production technique. Ruminal fluid for the in vitro gas production technique was prepared using the in vitro Hohenheim gas test method. The treatments were 1) control, 2) orange peel oil 300 ppm, 3) clove oil 300 ppm and 4) combination between clove oil 300 ppm and orange peel oils 300 ppm in ruminal fluid, which were assigned and analyzed in a two by two factorial arrangement in a completely randomized design. The results indicated that insoluble gas fraction (*b*; 40.8±0.80, 46.82±1.74, 40.36±1.31, 53.36±0.45 ml, respectively) and potential of the extent of gas production (|*a*|+ *b*; 43.01±1.20, 47.38±1.88, 42.96±0.94, 56.03±0.57 ml, respectively) were significantly different ($P < 0.01$) among the control, orange peel oil, clove oil and their combination. Soluble gas fraction (*a,ml*) and rate of gas production (c, ml/h) were not different among treatments. Clove and orange peel oils decreased methane production (12.31±0.69 ml/gDM and 14.90±0.54 ml/g DM, $P< 0.05$), compared to the control (18.15±0.52 ml/g DM). However, there were no additive or synergistic effects when they were used together in combination treatment for decreasing methane production (14.74±0.88 ml/g DM).

Keywords: clove oil, orange peel oil, rumen gas production, rumen methane production, in vitro gas production technique

INTRODUCTION: Public awareness of the potential health risk and environmental problem caused by the excessive use of in-feed antibiotics, growth hormones and certain pharmaceutical food production led to prohibition of certain antibiotics since 1998 in EU member states. Some aromatic herbs and essential oils which have been used for animal health management may substitute the use of growth promoters such as antibiotics and hormones. In vitro research of clove essential oils and eugenol reported that they had effect on all rumen fermentation products (Busquet et al., 2005; Castillejos et al., 2006). There are few experiments that use orange peel oils as a rumen modifier, but it was reported that it could increase dry matter and NDF digestibility (Gorgulu, 2010). The combination between essential oils may result in additive and/or synergic effects that may enhance efficiency of rumen microbial fermentation and nutrient utilization in ruminants. Thus, this research evaluated the effects of clove (CO, eugenol), orange peel (OP, limonede) essential oils and their combinations in an in vitro rumen fermentation system using the Hohenheim gas production technique (HGT).

1. MATERIAL AND METHODS: Three ruminal cannulated cows were used as donors of ruminal fluid. The cows were fed daily with a total mixed ration (TMR– 60% concentrated feed and 40% alfalfa hay) twice a day. The TMR was also used as a substrate in the in vitro rumen gas production technique. The TMR has 18.81% crude

protein (CP), 9.22 % CP acid-digestible insoluble crude protein (ADICP), 49.87% nitrogen-free extracts (NFE), 19.77% crude fiber (CF), 38.22% neutral detergent fiber (NDF) and 29.24% acid detergent fiber (ADF).

The estimation of metabolic energy (ME) of TMR was calculated by an equation from Boguhn et al (2003). Clove (CO) and orange peel (OP) essential oils were extracted using water from clove buds and orange peel. The chemical composition of clove and orange peel essential oil samples indicated that eugenol contained in clove oil is 97.26% and limonede contained in orange peel oil is 98.08%.

1.1. In vitro Gas Production Technique: Addition of CO, OP and their combination into rumen fluid were evaluated by the in vitro Hohenheim Gas Test (HGT). The operation of the HGT system is described in detail by Menke and Steingass (1979). Anaerobic techniques were used in all procedures during the rumen fluid transfer and incubation period. Rumen fluid was collected from rumen cannulated cows before morning feeding after 2 weeks feed adaptation. Filtered rumen fluid was added to the buffer medium in proportion 1: 2 v/v. CO and OP oils 300 ppm added to mixed rumen fluid and the buffer medium as a treatment of this experiment. Through the inlet of the HGT's glass syringes in which the substrate was placed, 30 ml of incubation mixed medium (rumen fluid, buffer medium and CO,OP or combination CO-OP) was then dispensed into the pre-heated HGT's glass syringe (39°C) with the help of a semi-automatic pipette. The incubation of GHT was conducted for 96 hours inside a modified water bath (39°C).

1.2. Gas Total and Methane Gas Measurement and Calculation: Gas production data was collected at 3, 6, 9, 12, 24, 48, 72 and 96 hours. After 6 h of incubation, methane gas was measured using a catharometer methane sensor OLC20. Cumulative gas production data were fitted to the model by Ørskov and Mcdonald (1979):

$$y = a + b(1\text{-}\exp^{-ct}).$$

Where: a, gas production from soluble fraction (ml). b, gas production from the insoluble fraction (ml). [a+b], potential gas production (ml). c, gas production rate constant for the insoluble fraction (ml/h). t, incubation time (h). y, gas produce at time t (ml).

1.3. Treatment and Statistical Analysis: The treatments were 1) control (CO-0 and OP-0) , 2) clove oil 300 ppm (CO300), 3) orange peel oil 300 ppm (OP300) and 4) clove oil 300 ppm + orange peel oil 300 ppm (CO300-OP300). A two (CO0-CO300 ppm) by two (OP0-OP300) factorial arrangement in a completely randomized designed was used to compare gas production kinetics and methane production using the General Linear model (GLM) of the SAS. The significance of differences between individual means was determined using Duncan's multiple comparison test.

2. RESULTS AND DISCUSSION: Addition of clove, orange peel essential oils and their combination (CO-OP) into TMR had significant effect on in vitro rumen gas total production, rumen methane production and metabolism energy of TMR after incubation (table 1).

2.1. Rumen Gas Production: Soluble gas fraction (a) and rate of gas production (c) did not differ among treatments. These data suggested that a lag phase due to delay in microbial colonization of the TMR may occur at the same time as incubation. The incubation TMR by using CO, OP and a combination between CO and OP had

significant effect on the insoluble gas fraction (b) and potential of the extent of gas production (|a|+b). The addition combination between CO and OP 300 ppm had a gas volume at a symptote (b) value higher than the control, but addition of CO 300 ppm had the same value as the control. The gas volume at asymptote (b) described the fermentation of the insoluble fraction. This result might have been a reflection of CO at 300 ppm having no negative effect on digestibility of the insoluble fraction of TMR, because CO was reported to inhibit enzyme CMCase, xylanase and acetylesterase at level 0.25 ml and 0.50 ml of extract (Patra, 2010). The combination effect of CO and OP showed a positive effect in increasing digestibility of the insoluble fraction of TMR due to a high value of gas production at asymptote (b) and total gas production at 96 h after incubation (P >0.05).

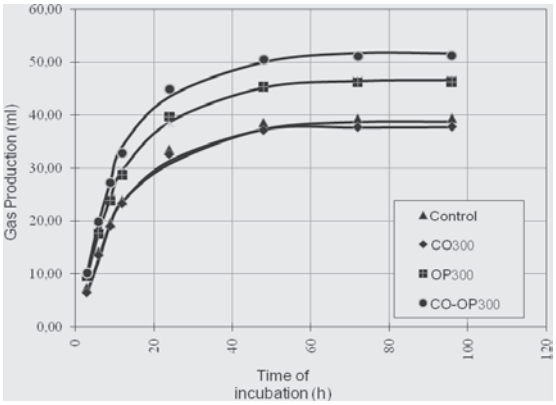

Figure 1. Cummulative gas volume estimated by $y = a + b(1\text{-}exp^{-ct})$ throughout 96 hours of addition of clove, orange peel oils and their combination to TMR.

Table 1. Characteristic and cumulative gas volume production throughout 96 hours of rumen incubation with TMR, CO, OP and combination between CO-OP at 300 ppm, CH_4 production at 6 hours incubation and Estimated ME.

Parameter		Control		OP300		CO300		CO-OP300	
		Avg	SE	Avg	SE	Avg	SE	Avg	SE
Gas character	a, ml	-1.38	0.48	-2.55	0.46	-2.60	0.48	-2.41	0.12
	b, ml	40.80c	0.80	46.82b	1.74	40.36c	1.31	53.62a	0.45
	c, ml/h	0.07	0.00	0.08	0.00	0.01	0.25	0.01	0.25
	a+b, ml	43.01c	1.20	47.37b	1.88	42.96c	0.94	56.03a	0.57
Gas prod.	6 h, ml	12.50b	0.12	17.65a	1.45	12.86b	0.53	19.63a	0.49
	24 h, ml	31.28c	0.20	38.60b	1.85	30.75c	0.69	43.43a	0.44
	48 h, ml	37.31c	0.36	45.14b	2.02	37.27c	1.11	49.97a	0.34
	96 h, ml	38.74c	0.61	46.58b	1.53	37.70c	2.42	51.65a	0.40
ME (MCal/KgDM)*		2.25c	0.00	2.33b	0.02	2.25c	0.01	2.37a	0.00
Methane %		26.55a	0.85	23.18b	0.64	14.71c	0.54	14.99c	0.64
Methane (ml/g DM)		18.15a	0.52	14.90b	0.54	12.31c	0.69	14.74b	0.88
MR (%)				17.89		32.16		18.77	

Where : MR = methane reduction, ME* = predicted by equation from Boguhn J et al (2003)
Same letter in the same row indicates no difference between treatment (P >0.05)

2.2. Rumen Methane Production: The addition of CO, OP and their combination reduced rumen methane production after 6 h incubation from the control (32.16%, 17.89% and 18.77%, respectively). The methane reduction value of addition of CO 300 ppm had nearly twice the value as addition of OP 300 ppm, but the combination of CO and OP had the same value of methane reduction with OP 300 ppm. This indicated that there was negative effect with addition of the combination due to eugenol activity or limonene activity in the rumen. However, there was no effect decreasing digestibility of the insoluble fraction of TMR.

2.3. Metabolism Energy: Addition of OP 300 ppm and combination CO and OP 300 ppm had no negative effect on gas production at 24 h after incubation, which led to an increase of estimated ME of TMR. Menke et al (1988) suggested that gas volume at 24 h after incubation has a relationship with ME in feedstuff. Addition CO 300 ppm had similar effect with the control but did not decrease the ME value of TMR (table 1).

CONCLUSION: Addition of orange peel oil 300 ppm, clove 300 ppm and their combination affected methane production compared to the control. However, there was no synergy effect on the methane production value for the addition combination between orange peel and clove. Methane gas reduction of the clove oils , orange peel oil and their combination due to efficiency of energy available in TMR from insoluble digestibility fraction of TMR (fraction b of gas characteristics and ME values were higher than control).

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SEEDING OF SELECTED COMPLEXES OF MICROORGANISMS ON LITTER DURING REARING TO REDUCE AMMONIA EMISSIONS IN BROILER HOUSES

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ABSTRACT: The aim of this study is to confirm the interest in seeding selected complexes of microorganisms on litter during broiler rearing. The trials were carried out on two kinds of broiler production (40d or 50d broilers) on 6 commercial farms. Each trial included monitoring of a "test" batch (T) receiving the litter treatment and an untreated batch (NT). Main results show a significant decrease in mortality rate of T batches for 50d broilers (-20.5%). For this production, the severity of pododermatitis was also significantly lower from 10-40 days of rearing. The mean total nitrogen content in solid manure tended to increase for both 50d broilers (+10.7%) and 40d broilers (+6.5%). Moreover, nitrogen losses decreased an average of 24.0% for 50d broilers and 19.2% for 40d broilers. Ammonia emissions also tended to decrease, by 8.5%. These results confirm the utility of this practice to reduce ammonia losses in livestock houses, and the impact on animal health and welfare is significant, especially for long rearing periods.

Keywords: poultry, mitigation strategy, nitrogen losses, ammonia emissions, seeding of microorganisms, solid manure, animal's welfare, litter fermentation

INTRODUCTION: Seeding a complex of selected microorganisms on litter during rearing appears to be a practice able to limit ammonia emissions in broiler houses while contributing to the welfare and health of animals (Aubert et al., 2011). The litter, initially a stable structure, will evolve during rearing and become a biological reactor. Animal manure will allow the development of microorganisms, which need water, nitrogen and energy to develop. Seeding selected microorganisms in a litter can guide the development and change the microbial degradation of organic matter. The aims of this study are to evaluate the impact of this practice on reducing nitrogen emissions, and particularly ammonia emissions, in commercial farms, but also on animal health and welfare and manure quality.

1. MATERIAL AND METHODS: The trials were carried out on six commercial farms rearing broilers in Brittany (France) in 2010 and 2011. Each trial included monitoring of two broiler houses situated on the same farm, with similar dimensions, equipment, and mechanical ventilation. The litter of "test" broiler house (T) was seeded with a complex of microorganisms during rearing. In the first 3 farms, seeding was done once, early in the batch (at 10 days) with a complex of bacteria and fungi in the form of powder (Bacteriolit® concentré, SOBAC). In the others, seeding was done several times throughout the batch, with a complex of bacteria sprayed on the litter in liquid form (Bactivor®, GBP environment). The "untreated" broiler house (NT) did not receive any litter treatment. The first farm produced heavy broilers (50d broilers), slaughtered at 50 days of age, with a mean liveweight of 2.60 kg and 5.86 kg of straw/m² for litter, brought in once at the beginning of the batch. The five other farms produced standard broilers or lightweight broilers (40d broilers), slaughtered at 40 days of age, with a mean liveweight of 1.61 kg and 3.5 kg of straw/m² for litter.

1.1. Visual aspect of litter quality and evaluation of the severity of pododermatitis: An overall evaluation of the quality of the litter (dry and crumbly, or moist and crusty) was given in each building, at the beginning, middle and end of the batch. The foot state of the broilers was scored using a scoring grid taking into account the surface area of the lesion and its severity. The observations were performed at the beginning, middle and end of the batch on about 50 randomly sampled animals per broiler house.

1.2. Characterization of solid manure composition and estimation of nitrogen losses: Physico-chemical analyses were performed on the solid manure from broiler houses T and NT at the end of the batches and after removal of the animals. Solid manure sampling was conducted at several sites in the building (15-20 samples pooled and thoroughly mixed). All the solid manure from each broiler house was weighed at the end of each batch. Nitrogen losses through volatilization in broiler houses (mainly NH_3, but also N_2O and N_2) were estimated using mass balance on nitrogen parameters at the livestock house level. The nitrogen losses corresponding to the proportion of nitrogen excreted by animals which was not found in the solid manure at the end of the batch was assumed to be lost by volatilization. Furthermore, ammonia emissions were estimated with the simplified method of measurement of greenhouse-gas emissions in livestock houses (Ponchant et al., 2009). Ammonia concentrations were quantified by photoacoustic infrared spectrometry (INNOVA 1412) from air samples taken inside and outside the broiler house at the beginning, middle and end of rearing.

2. RESULTS AND DISCUSSION:

2.1. Animal performance: All batches were conducted identically in broiler houses T and NT, particularly animal housing densities and litter inputs (Table 1). No significant differences appeared in the mean liveweight or feed conversion (less than 1% difference). However, a significant decrease in mean mortality rate (20.5%) was observed in T batches of 50d broilers but not of 40d broilers. The mortality rates for this kind of production were relatively low in these trials.

Table 1. Effect of treatment on animal performance.

	50d broilers (n=8)			40d broilers (n=17)		
	NT	T	Mean difference	NT	T	Mean difference
An. H. Density A/m²	20.8 ± 0.1	20.8 ± 0.2		29.4 ± 1.9	29.1 ± 2.0	
Litter kg/m²	5.9 ± 0.3	5.9 ± 0.3		3.5 ± 1.3	3.5 ± 1.3	
Mort. rate %	4.39 ± 1.04	3.44 ± 1.02	-20.5% *	1.82 ± 0.90	1.85 ± 0.76	+13.8% (ns)
LW kg	2.61 ± 0.07	2.60 ± 0.05	+0.02% (ns)	1.60 ± 0.23	1.61 ± 0.22	+0.91% (ns)
FC	1.93 ± 0.06	1.92 ± 0.05	-0.44% (ns)	1.83 ± 0.11	1.82 ± 0.10	-0.03% (ns)

Statistical test used: Wilcoxon signed rank test for paired samples; ns: not significant; *: p-value < 0.05

2.2. Aspect of litter and severity of pododermatitis: The general aspect of litter degraded over batches both treatments (T & NT). However, they appeared drier on average at the end of rearing for T batches. Also, for 50d broilers, litter treatment significantly decreased severity of pododermatitis observed at 10, 20 and 40 days of rearing ($p<0.05$, Mann-Whitney U test for ordered variable). Nevertheless the effect was not significant after the departure of females (after 40 days of rearing). No treatment effect was visible for 40d broilers.

2.3. Composition of solid manure: The results of solid-manure composition confirm visual observations performed on litter at the end of rearing. For 50d broilers, the mean dry matter (DM) content difference equalled +7.3%, but the difference was not significant (Table 2). In contrast, for 50d broilers, there was a non-significant increase in total nitrogen content (Ntk) (+10.7%). This trend was accompanied by a decrease in the ratio between ammonia nitrogen content and total nitrogen content (N-NH_4/Ntk) (-15.2% for NT). For 40d broilers, there was a significant increase in Ntk of treated solid manure, (+6.46% for NT). However, the mean N- NH_4/Ntk ratio appeared to be similar for T and NT batches. Moreover, for 40d broilers, the mean C/N ratio decreased significantly (by 4.2%) in T batches.

Table 2. Effect of the treatment on composition of solid manure at the end of rearing.

	50d broilers (n=7)			40d broilers (n=17)		
	NT	T	Mean difference	NT	T	Mean difference
DM (%)	59.2 ± 7.4	63.0 ± 3.1	+7.2% (ns)	58.7 ± 7.3	59.4 ± 6.7	+1.6% (ns)
Ntk (%)	2.4 ± 0.3	2.6 ± 0.6	+10.7% (ns)	2.5 ± 0.3	2.7 ± 0.3	+6.5% *
N-NH_4 /Ntk (%)	23.7 ± 3.3	21.0 ± 4.4	-15.2% (ns)	19.2 ± 2.9	19.5 ± 4.0	-0.8% (ns)
C/N	12.4 ± 1.4	12.0 ± 1.4	-1.9% (ns)	11.7 ± 1.6	11.2 ± 1.5	-4.2% *

Statistical test used: Wilcoxon signed rank test for paired samples; ns: not significant; *: p-value < 0.05

2.4. Nitrogen losses in broiler houses: The results show a decrease in mean nitrogen losses through volatilization, which is consistent with an increase in total nitrogen content in solid manure at the end of rearing. For 50d broilers, mean nitrogen losses were 24.0% lower (Table 3), but not statistically significant. For 40d broilers, there was a significant decrease in mean nitrogen losses (by 19.2%).

Table 3. Effect of the treatment on nitrogen losses in broiler houses.

	Broilers 50d (n=7)			Broilers 40d (n=17)		
	NT	T	Mean difference	NT	T	Mean difference
N entering (g/broiler)	151 ± 8	150 ± 5		90 ± 9	90 ± 9	
N excreted (g/broiler)	72 ± 5	71 ± 3		42 ± 5	42 ± 4	
N manure (g/broiler)	52 ± 4	56 ± 10		28 ± 6	30 ± 7	
N losses (% N excreted)	27.5 ± 8.7	21.2 ± 12.9	-24.0% (ns)	33.1 ± 15.3	28.5 ± 16.3	-19.2% **

Statistical test used: Wilcoxon signed rank test for paired samples; ns: not significant; **: p-value < 0.01

Nitrogen losses calculated in these trials are similar (or lower for 50d broilers) than those adopted by CORPEN (2006), i.e. 30% of the nitrogen excreted by animals. The amounts of nitrogen excreted were similar between the control and treatment (T & NT) for both 40d and 50d broilers. Furthermore, mean ammonia emissions in broiler houses tended to decrease for T batches (by 8.5%, Table 4). Nevertheless, an increase in mean nitrous oxide emissions of 16.7% was observed, which is consistent with a drier litter. Carbon dioxide emissions differed little (mean difference 1.9%). These findings should be interpreted with caution because observed emission differences were not statistically significant.

Table 4. Effect of the treatment on ammonia and GHG emissions in broiler houses.

(n=17)		NT	T	Mean difference
C-CO_2 emissions		880 ± 259	859 ± 243	-1.9% (ns)
N-NH_3 emissions	g/animal	3.4 ± 2.3	3.2 ± 3.2	-8.5% (ns)
N-N_2O emissions		0.6 ± 0.3	0.6 ± 0.3	+16.7% (ns)

Statistical test used: Wilcoxon signed rank test for paired samples; ns: not significant

CONCLUSION: These trials show that the seeding of selected complexes of microorganisms on litter during rearing tends to decrease nitrogen losses through volatilization in broiler houses, especially ammonia losses. Nitrogen tends to be better preserved in solid manures and to reorganize into different forms. This practice also appears to contribute to animal health and welfare by decreasing mortality rate and pododermatitis, especially during long rearing periods. The decrease in ammonia concentration in broiler houses may also decrease respiratory diseases in animals or human workers. However, differences between NT and T batches differed from one trial to another and from one farm to another. The effects observed on parameters examined were not always significant. Several factors not controlled under commercial conditions may explain this variability. For example, the occurrence of digestive disorders in animals and antibiotic use are likely to disturb litter evolution. The role of animal behaviour and duration of the rearing period may also have an influence. The results are encouraging in terms of health, animal welfare and environment, especially for production requiring long rearing periods, but additional studies should be conducted to understand better the factors influencing the observed effects.

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USE OF HEAT FROM ANAEROBIC DIGESTION TO IMPROVE THE NITRIFICATION-DENITRIFICATION PROCESS. INITIAL RESULTS FROM A PILOT PLANT

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ABSTRACT: Within manure management strategies, treatment facilities aiming at reducing the nitrogen content of effluent to be spread on fields do not have to become a source of pollution themselves through transferring the problem from soil and water to the atmosphere.
In this context, an interesting solution for the treatment of slurry that meets both requirements is the nitrification-denitrification (DN-N) process. The biological reactions that occur in a DN-N plant remove nitrogen as N_2, an inert gas in the atmosphere, thus reducing further fermentation and the consequent emission of nitrogen from the following storage and land spreading operations.
Nitrification is positively affected by temperature. According to Monod kinetic, a nitrogen removal rate at 30 °C is three times greater than the amount that can be processed at 20 °C. This has been verified through an experimental test using a DN-N pilot plant operating with swine liquid manure. The nitrogen removal rate increased from 1.5 gN-NH_4/d to more than 8 g N-NH_4/d.
At a farm-scale, to warm the nitrification reactor, the heat generated by the CHP unit of a biogas plant can be used.
Keeping a high and constant temperature in the nitrification reactor allows a steady nitrification-dentirification process during the entire year, and the possibility, when needed, to increase the load without increasing the volume of tank reactors.

Keywords: nitrification-denitrification; temperature; anaerobic digestion; heat

INTRODUCTION: It is common knowledge that biological processes are positively influenced by temperature. Optimum values for nitrification (as well as for denitrification) are around 30 °C (Daumer et al., 2005). The effect of temperature on microbial activity can be described by the following equation 1 (Vismara, 2002), a Monod kinetics-based equation which outlines that removal rate at a given temperature (ν_T) depends on the removal rate at the reference temperature (ν at 20 °C, ν_{20}) and on temperature through the coefficient θ (1):

$$\nu_T = \nu_{20} * \theta^{(T-20)} \qquad (1)$$

For nitrification, ν_{20} and θ values are 2.4 g N-NH_4/g SSV•d and 1.12 (Vismara, 2002); from 20 °C to 30 °C and at non-limiting oxygen conditions (> 2 mg/L DO as reported by Vismara, 2002) the nitrogen removal rate triples from 2.4 to 7.4 g N-NH_4/g SSV•d. Normally, nitrification reactors at the farm-scale are not thermostated. The temperature in the reactor is about 20 °C, but with large fluctuations of 10-15 °C depending on the climatic zone. Measurements from a biological plant located in the Finistère region show that in the nitrification reactor there is an average 20 °C temperature in winter, 25-27 °C in summer, and with minimum and maximum values of 15 and 30 °C, respectively. Increasing the temperature of the mixed liquor and keeping it constant during the entire year results in steady microbial conditions and in

the possibility to increase the influent load, reactors' volume and nitrogen removal efficiency being equal.
For this purpose, the heat generated by the CHP unit of a biogas plant can be used. The aim of this study was to verify the influence of temperature on increasing the nitrogen removal rate (described by equation 1) in the biological treatment of swine wastewater.

1. MATERIAL AND METHODS: To verify this hypothesis, a DN-N pilot plant was used. It consists of two 30 L reactors, one for the aerobic and one for the anoxic phase; both are warmed by a thermostatic bath. Operational conditions are those of a CSTR, with suspendend biomass and continuous flow, without sludge recirculation. Raw slurry enters the denitrification reactor while treated effluent is discharged from the aerobic reactor.
Analyses of raw slurry were performed every week (pH, conductivity, total suspended solids TSS, total Kjeldhal nitrogen TKN, ammonia N-NH_4, chemical oxygen demand COD), and those of aerated and denitrificated mixed liquor every two days (pH, conductivity, dissolved oxygen DO, TSS and volatile suspendend solids VSS, TKN, N-NH_4, COD). Measurement of influent flow rate and nitrite and nitrate concentrations in the aerated and anoxic reactor were peformed daily. Analyses were carried out according to APHA, 2005 standards methods, except for nitrate and nitrate determination, which were performed using colorimetric test strips.

2. RESULTS AND DISCUSSION: Two tests were performed for a total of 45 days, the first at 20 °C, followed by one at 30 °C. The aim of the tests was to verify, if equal, other main conditions such as influent characteristics and active sludge concentration at non-limiting oxygen conditions, whether increasing the temperature by 10 °C in the nitrification reactor could result in a tripled nitrogen load, as stated by equation 1.
For the start-up, the DN-N plant was inoculated with active sludge from a plant operating on slaughterhouse wastewater. It was then fed with decanted pig slurry, whose characteristics are summarized in Table 1.

Table 1. Characteristics of the influent used for DN-N tests.

parameter	unit	average value
TSS	g/L	1.08
TKN	mg/L	1,008
N-NH_4	mg/L	812
COD	mgO_2/L	6,507
soluble COD	mgO_2/L	3,605
pH		8.2
conductivity	mS/cm	10.3

Because of the low soluble COD/TKN ratio, it was necessary to add an external carbon source (saccharose) at about 1,500 mg/L, to reach over the minimum value of 6.5 (Eurotec and TeSAF Department internal reports), thus providing a good denitrification performance; pH was kept within the 7-8 range and DO above 2.5-3 mgO_2/L. As shown in Figure 1, when temperature rose from 20 °C to 30 °C, influent flow increased from a maximum of 1.8 L/d (corresponding to 1.5 gN-NH_4/d) to a maximum of 9.2 L/d (corresponding to 8.2 g N-NH_4/d); concurrently, nitrogen removal efficiency was stable at a value of more than 99%. Moreover, the low residual ammonia concentration in the outflow (< 5.6 mg N-NH_4/L), the absence of

nitrites and the low nitrate concentration (< 45 mg $N\text{-}NO_3$/L) confirm the correct progress of the DN-N process. Results indicate that a 10 °C rise in temperature enabled the five-fold increase of the influent flow: thus, expectations based on equation 1 were not only confirmed, but also surpassed. This occurred because of the "biomass activity factor". This factor depends on the age of sludge: starting from a value of 1 for an age of 0 days, it decreases following an exponential curve as the age of sludge increases. In the test at 20 °C, the flow rate was very low. To have a good nitrification performance, the sludge age was kept at high values, and as a consequence biomass activity was depressed. Moving from 20 °C to 30 °C allowed a higher flow rate: age of sludge decreased, and the biomass activity factor increased.

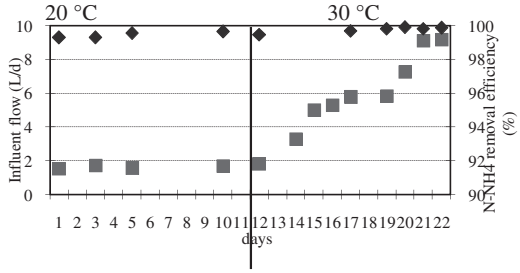

Figure 1. Flow rate (L/d, squared points) and nitrogen removal efficiency (%, diamond points) during the two DN-N tests at 20 °C and 30 °C. Nitrogen removal efficiency was calculated based on the $N\text{-}NH_4$ concentration in the influent and in the aerated mixed liquor. Vertical line marks the transit from 20 °C to 30 °C.

CONCLUSION: Nitrification-denitrification plants for nitrogen removal from livestock effluents generally work at ambient temperature, 20 °C, on average, but with wide seasonal 10-15 °C fluctuations. Nevertheless, the biological nitrification process is positively influenced by temperature. According to Monod kinetics, the nitrogen removal rate at 30 °C is three times greater than the amount that can be processed at 20 °C, reaction volumes and nitrogen removal efficiency being equal. At a farm scale, this means the opportunity to triple the influent flow without increasing reactors' volumes.

For this purpose, the heat produced by the CHP unit of a biogas plant can be used, without wasting it in the atmosphere, as usually occurs for the amount exceeding the needs of the digestor.

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EFFECT OF SLURRY MIXING ON AMMONIA EMISSIONS FROM A DAIRY BARN WITH SUBFLOOR STORAGE

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ABSTRACT: Several studies have shown that housing systems and manure removal strategies strongly influence ammonia (NH_3) emission levels from dairy cow barns. This investigation focused on NH_3 emissions from a typical naturally cross-ventilated free-stall dairy barn in Germany. Measurements occurred from March to August 2011 and covered spring and summer. Two sections of the barn, which were separated by a foil partition, were investigated separately. Each section was designed for 48 Holstein cows with a live weight of 700 kg and milk production of 34 kg per day. Both sections had a slatted floor with shared subfloor storage of liquid manure and a robot system for fully automated water-cleaning of the slatted floor. The slurry stored in the pit was homogenised twice a day for a duration of 30 minutes. Since the mixer for homogenising the liquid manure beneath the slatted floor was located at the gable wall next to section 1, a high intensity of homogenisation of slurry existed in section 1 with a lower intensity in section 2. Gas concentrations were measured above the feed alley at the lee side of the barn using a photo-acoustic multi-gas analyser. The air exchange rate was calculated by the tracer gas decay method using a SF_6 electron capture detector. The lower intensity of manure homogenisation beneath the slatted floor led to 23% lower NH_3 emissions (34.6 ± 22.8 g LU d^{-1}) than slatted floor with intensive slurry mixing (45.1 ± 23.9 g LU d^{-1}).

Keywords: ammonia**,** NH_3, slurry, cattle, emission, homogenisation

INTRODUCTION: Reducing environmental pollution from livestock is an important policy in meeting future sustainability criteria. Substantial data on emissions is necessary to give recommendations for barn construction and equipment, as well as for management strategies. Several studies have shown that housing systems and manure removal strategies strongly influence ammonia (NH_3) emission levels from dairy cow barns (Braam et al., 1997; Morsing et al., 2008). It is also known that temperature emerges as a significant variable that influences NH_3 emission from manure (Zhang et al., 2005). Furthermore, the urea content of the tank milk may significantly influence the level of NH_3 emissions (Schrade et al., 2012). Hence, there are several system and external variables affecting the potential of NH_3 generation, making it a complex task to determine the impact of individual influencing factors. This investigation focused on NH_3 emissions from two equivalently designed and managed sections within a naturally cross-ventilated, free-stall dairy barn in Germany.

1. MATERIAL AND METHODS: Measurements were performed in North-Western Germany from March to August 2011 for more than 100 days covering spring and summer seasons. The free-stall dairy barn was cross-ventilated with no outside walls at the eave sides of the building. Measured from floor level, the eave height was 5.15 m and the ridge was 13 m high. The total area available per cow was 10 m^2; 7 m^2 per cow was used as walking area ('emitting surface area'); the remaining area was used for laying and feeding. Two sections of the barn, which were separated by a foil partition, were investigated separately for their NH_3 emissions. Each section was designed for 48 Holstein cows with a live weight of 700 kg and milk production of 34

kg per day. Milking was performed twice a day in a separate milking house. Both sections of the barn had a slatted floor with shared subfloor storage of liquid manure and a robot system for fully automated water-cleaning of the slatted floor. The slurry stored in the pit was homogenised twice a day for a duration of 30 minutes. Since the mixer for homogenising the liquid manure beneath the slatted floor was located at the gable wall, there was one section with high intensity of slurry homogenisation and the second section with lower intensity.

Gas concentrations were measured in the exhaust air using a photo-acoustic multi-gas analyser 1412 and a multiplexer 1303 (Lumasense Technologies SA, Ballerup, Denmark). Each section was equipped with eight sampling points in line above the feed alley (exhaust air side of the barn), which were combined to produce one aggregate sample for each section. Sampling tubes were located 4 meters above floor level. In each section the air was sampled by a vacuum pump through 8 mm (inner diameter) polytetrafluoroethylene (PTFE) tubes. The air exchange rate was calculated by the tracer gas decay method using a SF_6 electron capture detector (Niebaum, 2001; Schneider, 2006). The building's calculated air exchange rate was correlated to the respective wind conditions outside the barn.

2. RESULTS AND DISCUSSION: NH_3 emissions were 45.1 ± 23.9 and 34.6 ± 22.8 g LU d^{-1} for the slatted floor sections with high and low intensity of slurry mixing, respectively. Thus, the lower intensity of manure homogenisation beneath the slatted floor led to 23% lower NH_3 emissions than the slatted floor with intensive slurry mixing (Fig.1). The level of NH_3 emissions in spring (18.5 and 28.2 g NH_3 LU^{-1} d^{-1}) corresponds with the results of Ngwabie et al. (2009) in March with a partially slatted floor. Samer et al. (2011) have reported a slightly higher level of emissions during summer. However, cleaning floors with water, as the automatic cleaning robot for the slatted floor sections in this investigation, may have contributed to the NH_3 emission reduction, as also reported by Kroodsma et al. (1993). The reported emission rates are only representative for spring and summer and are not transferable to the entire year since temperature strongly influences the level of emission (Ngwabie et al., 2011; Sommer et al., 2007).

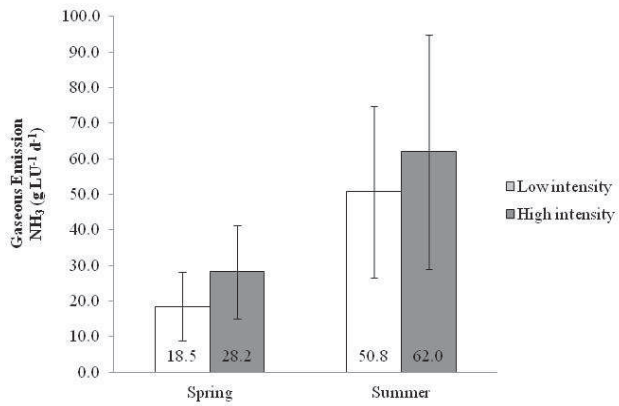

Figure 1. NH_3 emissions from slatted floor sections with high and low intensity of homogenisation of liquid manure beneath the slatted floor.

CONCLUSION: The lower intensity of manure homogenisation beneath the slatted floor led to 23% lower NH_3 emissions (34.6 ± 22.8 g LU d^{-1}) than the slatted floor with intensive slurry mixing (45.1 ± 23.9 g LU d^{-1}).

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EFFECTS OF BEDDING ADDITIVES ON NITROGEN LOSSES DURING STORAGE OF CATTLE STRAW MANURE AND MAIZE NITROGEN RECOVERY AFTER FIELD APPLICATION

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ABSTRACT: Considerable amounts of nitrogen (N) are lost from manure in straw-based cattle housing systems as dinitrogen (N_2), ammonia (NH_3) and nitrous oxide (N_2O) emissions. The objectives of this study were (i) to quantify the mitigating effects of three promising bedding additives, i.e. zeolite, lava meal and sandy farm topsoil on total N, NH_3-N and N_2O -N losses during storage of cattle straw manure and (ii) to determine the apparent N recovery of manure in a maize field experiment. The bedding additives were applied inside a naturally ventilated sloping-floor barn proportional to the daily straw dosage of 5 kg per livestock unit, i.e. 10% zeolite, 20% lava meal and 33% sandy farm topsoil. The trampled-down straw manure was collected daily over an 80-day period and then stockpiled inside a roofed building. Manure storage continued for another 80 days after the end of the collection period. NH_3 and N_2O emissions during this period were measured, and N balances were quantified. After storage, the manure was incorporated into sandy soil and maize was sown after one week of incorporation. Dry matter (DM) yield and apparent N recovery of manure were determined over a 3-month growing period. Total N losses during storage were reduced by 49% by zeolite compared to the control and 40% each by the farm topsoil and lava meal. On average, 98% of these losses were unaccounted for and probably constituted harmless N_2 gas. All three additives remarkably reduced total NH_3-N and N_2O-N emission rates by approximately 76% compared to the control. This could be attributed to the adsorption of ammonium (NH_4+) by zeolite, lava meal and farm topsoil and possible formation of struvite salt ($NH_4MGPO_4.6H_2O$) by lava meal. Maize DM yield increased from 12.6 Mg ha^{-1} (control) to 14.8 Mg ha^{-1} by lava meal, 15.5 Mg ha^{-1} by farm topsoil and 16.3 Mg ha^{-1} by zeolite. The apparent N recovery increased from 11% (control) to 30% each by farm topsoil and lava meal, and 44% by zeolite. This might be due to prevention of nitrate leaching through NH_4^+ adsorption by additives, as unusually heavy rainfall occurred after manure incorporation into the soil before maize sowing and during its growing period. In conclusion, potential exists for using bedding additives to improve the agro-environmental value of straw-based animal-welfare-friendly cattle housing systems by mitigating NH_3-N and N_2O-N emissions, reducing total N losses, and improving crop N recovery.

Keywords: cattle straw manure, bedding additives, total N losses, NH_3 emission, crop N recovery

INTRODUCTION: Animal husbandry contributes substantially to anthropogenic ammonia (NH_3) and nitrous oxide (N_2O) emissions. NH_3 emissions can cause acidification and eutrophication problems after dry and wet deposition and thus play a significant role in the deterioration of biodiversity (Amon et al., 2001). N_2O is a potent greenhouse gas that traps heat and adds to global climate change (Akiyama and Tsuruta, 2003). These emissions occur at each phase of the manure management

chain, i.e. animal housing, manure storage and manure field application. Abatement measures during animal housing and manure storage have shown diverging NH_3 emission rates following land application (Kirchmann and Lundvall, 1998). The control of N losses during one phase could enhance them in subsequent phases (Rotz, 2004). Therefore, it is crucial to develop and evaluate effective measures that can reduce emissions throughout the whole manure management chain and increase N use after land application. The objectives of this study were to (i) quantify the mitigating effects of three promising bedding additives, i.e. zeolite, lava meal and sandy farm topsoil on total N, NH_3-N and N_2O-N losses during storage of cattle straw manure and (ii) determine the apparent N recovery of manure in a maize field experiment.

1. MATERIALS AND METHODS: This study was performed at the Organic Experimental and Training Farm Droevendaal, located 1 km north of Wageningen, the Netherlands (55°99'N, 5°66'E).

1.1. Animal housing phase: The housing system was a naturally ventilated straw-bedded sloping-floor barn where four barn units were used for four treatments: straw application (control) and straw application followed by the addition of sandy farm topsoil, lava meal and zeolite. Each barn unit had a 42-m^2 bedding area and a 21-m^2 manure alley where a group of eight young beef bulls were kept. The bedding areas of all barn units were completely cleaned prior to the start of the experiment. Chopped wheat and barley straw were applied at a daily rate of 5 kg per livestock unit (LU) through broadcast spreading on the bedding areas (1 LU = 500 kg of live body weight). Sandy farm topsoil, lava meal and zeolite were used at percentages of 33, 20 and 10% of the daily straw dosages based on mass, respectively. These percentages were selected after a preliminary trial in which effects of applying various proportions of each additive on NH_3 emission from the straw manure bedding were evaluated (results not presented). The selection criterion for this was to achieve a minimum reduction of at least 80% compared to the control.

Zeolite (clinoptilolite) was purchased from Zeolite products®, Arnhem, the Netherlands (http://www.zeolite-products.com/). Its chemical composition was provided by the company. Farm topsoil was air-dried sandy soil of the farm where this study was performed. It was obtained by excavating the topsoil to a depth of 25 cm in a field previously cultivated with spring wheat. It had a 4% clay content. The soil's chemical composition was determined according to the standard procedures described by Houba et al. (1989). Lava meal (Eifelgold®) in powder form and its chemical composition was provided by Lava-Union® Germany. The chemical compositions of the additives are presented in (Table 1).

Table 1. Application rate (kg per Livestock Unit per day), composition and characteristics of the bedding additives.

Additive	Application Rate	Total N	Mineral N	Om†	P_2o_5	Mgo	Cec‡‡	PH-$Cacl_2$
	(Kg Lu^{-1} day^{-1})		(G Kg^{-1} Dry Matter)				(Cmol Kg^{-1})	
Zeolite	0.5	0.001	0	0	0.2	0.9	90	7.8
Farm Topsoil	1.7	1.2	0.13	29	0.4	N.D.‡	2	4.9
Lava Meal	1.0	0.002	0	0	10.0	85.0	12	7.9

† OM, organic matter; ‡ n.d., not determined; ‡‡ CEC, cation exchange capacity.

1.2. Manure storage phase: From each barn unit, the straw manure that bulls trampled down on the manure alley was manually collected twice daily (early morning and late afternoon) over an 80-day period (housing phase; see Shah et al. (in review) for full details). After collection, it was weighed and stockpiled inside a roofed building as four separate heaps: untreated straw manure (control) and straw manure amended with zeolite, lava meal and sandy farm topsoil. For this purpose, four compartments were constructed on a concrete floor by using 1.5-m-high concrete block walls. Each compartment was 4 m x 3 m x 1.5 m in size and lined with impermeable plastic sheeting to avoid leaching. Manure storage continued for another 80 days after the end of the collection period.

1.2.1. Estimation of NH_3 and N_2O fluxes during manure storage: Measurements of NH_3 and N_2O emissions during the storage phase were performed using a static flux chamber system with internal gas recirculation connected to a photoacoustic gas monitor (INNOVA 1412A, Denmark; Teye and Hautala, 2010; Predotova et al., 2010) by two Teflon tubes (inner diameter, 3 mm). At each measurement event, the flux chamber having a bottom sharp edge was pressed 4-5 cm deep into the surface of the manure heap. Thereafter, time patterns of NH_3 and N_2O concentrations were recorded every 10-15 minutes. Actual NH_3 emission rates were derived from the initial slope of the curve between NH_3 (gas) concentration (mg m^{-3}) and time (minutes) using a fitting procedure based on the non-rectangular hyperbola. Instantaneous N_2O emission rates were determined by the average linear slope of the data between N_2O concentration (mg m^{-3}) and time (min). For further details see Shah et al. (in review).

1.2.2. Total N losses: From each manure heap, total gaseous N losses during the 80-day storage period were calculated according to the mass balance method (Sommer and Dahl, 1999). Periodic emission totals of NH_3-N and N_2O-N were calculated by averaging the emission rates between two consecutive sampling points and multiplying by the number of days between these two points (Chadwick, 2005). Subsequently, emission values were summed throughout the whole storage period. Finally, the N losses unaccounted for (UNL) as a percentage of the established total gaseous N losses (TNL in g Mg-1 of initial fresh manure) were calculated by:

$$UNL\ (\%\ of\ total\ losses) = \frac{TNL - Total\ NH_3\text{-}N - Total\ N_2O\text{-}N}{TNL} \times 100 \qquad (1)$$

1.3. Manure application phase:

1.3.1. Experimental set up: After storage, each manure type was incorporated into the top 10 cm of an arable field on the farm, using 15 m x 4.5 m plots and an application rate of 170 kg N ha^{-1}. The experiment was set up as a randomised complete block design with four replicates. Treatments were (i) unfertilised (zero), (ii) untreated straw manure (control), (iii) straw manure amended with zeolite, (iv) straw manure amended with sandy farm topsoil and (v) straw manure amended with lava meal. One week after manure incorporation, silage maize (cv. Lapriora) was sown at a 6-cm depth with a density of 11 plants m^{-2}. Each plot had 6 rows of plants with 75-cm row spacing.

1.3.2. Maize dry matter (DM) yield and apparent N recovery (ANR): Maize was harvested after a 3-month growing period. At random, ten plants from two inner rows of each plot were cut at ground level. Fresh yield was measured in the field by weighing the total harvested aboveground plant biomass. Subsequently, the plants were chopped, and a representative sample of approximately 500 g was taken for

further analysis. Each sample was oven-dried at 70°C for 48 hours to determine DM yield, and the dried samples were ground to pass through a 1-mm sieve and analysed for total N content. Total N was determined following Kjeldahl digestion of the plant material. Maize ANR was calculated as:

$$ANR\ (\%) = \frac{(N_m \times DM_m) - (N_0 \times DM_0)}{TN_a} \times 100 \quad (2)$$

where N_m is the maize N content (kg N (Mg DM)$^{-1}$) in the manured plots, DM_m is the maize DM yield (Mg ha^{-1}) in the manured plots, N_0 is the maize N content (kg N (Mg DM)$^{-1}$) in the unfertilised plots, DM_0 is the maize DM yield (Mg ha^{-1}) in the unfertilised plots and TN_a is the total N amount applied with manure (kg ha^{-1}).

2. RESULTS AND DISCUSSION:

2.1. Total N losses during storage: Total N losses (% of initial) were highest for the control and lowest in the zeolite treatment. They were reduced by 49% due to addition of zeolite compared to the control and by 40% each by farm topsoil and lava meal (Table 2).

Table 2. N balance during the 80-day storage period.

Treatment	N Balance			
	Initial N	Final N	Difference	Total N Losses
	(Kg Mg^{-1} Of Initial Fresh Manure)			(% Of Initial)
Control	4.3	2.8	1.5	35 (100)†
Zeolite	4.4	3.6	0.8	18 (51)
Farm topsoil	4.3	3.4	0.9	21 (60)
Lava meal	3.9	3.1	0.8	21 (60)

† Values between parentheses in the same column represent relative losses compared to the control.

2.2. Gaseous emissions during storage: During storage, total NH_3-N and N_2O-N emission rates were lowest from the bedding additive treatments (on average, 9.9 g Mg-1 of initial fresh manure) and highest from the control (40.6 g Mg-1 of initial fresh manure). Application of lava meal, farm topsoil and zeolite reduced these losses by 84, 73 and 70% relative to the control, respectively (Table 3). This could be attributed to the adsorption of ammonium (NH_4+) by all of the additives and possible formation of struvite salt (ammonium magnesium phosphate hexahydrate; $NH_4MgPO_4.6H_2O$) by the lava meal. Adsorption processes of NH_4+ reduce NH_3 (aqueous) concentrations in the manure solution with lowered NH_3 (gas) emission rates as a result (Ndegwa et al., 2008). Moreover, also the occurrence of nitrification and subsequent denitrification processes will be retarded (Zaman and Nguyen ,2010). After field application, NH_4+ will be slowly released and become available for plant uptake (Shah et al., 2012).

On average, 2% of the total N losses through each treatment system occurred as NH_3-N and N_2O-N emissions, while the remaining 98% were unaccounted for (Table 3). In all probability, the majority of the unaccounted losses constituted harmless N_2 (Harper et al., 2000).

Table 3. Total measured and unaccounted N losses during the 80-day storage period.

Treatment	Total measured N losses				Unaccounted N losses	
	NH_3-N	N_2O-N	Total	of total N losses	of initial	of total N losses
	(g Mg^{-1} of initial fresh manure)				(%)	
Control	25.3	15.3	40.6 (100) †	3	34	97
Zeolite	3.2	9.0	12.2 (30)	2	18	98
Farm topsoil	3.6	7.2	10.8 (27)	1	21	99
Lava meal	2.7	4.0	6.7 (16)	1	21	99

† Values in parentheses in the same column represent relative losses compare to the control.

2.3. Maize DM yield and ANR: The application of each additive resulted in higher ($P < 0.05$) maize DM yield, N uptake and ANR compared to the control (Table 4). Reduced losses of mineral and easily degradable organic N compounds during the storage phase and prevention of nitrate leaching through NH_4^+ adsorption by the additives after field application were the most likely causes. Unusually heavy rainfalls occurred after manure incorporation into the soil before sowing the maize and also afterwards.

Increases in DM yield, N uptake and ANR were highest for the zeolite treatment (Table 4). This could be ascribed to its much higher cation exchange capacity (CEC) of 90 cmol kg^{-1} compared to that of lava meal (12 cmol kg^{-1}) and sandy farm topsoil (2 cmol kg^{-1}) (Table 1).

Table 4. Total maize dry matter (DM) yield, N uptake and apparent N recovery (ANR).

Treatment	Dm Yield (Mg Ha^{-1})	N Uptake (Kg Ha^{-1})	Anr (%)
Zero	$11.2^a \pm 0.1$†	$156^a \pm 3.2$	
Control‡	$12.6^a \pm 0.3$	$174^b \pm 4.7$	$11^a \pm 2.8$
Zeolite	$16.3^b \pm 0.7$	$230^d \pm 6.6$	$44^c \pm 4.3$
Farm Topsoil	$15.5^b \pm 1.1$	$206^c \pm 7.1$	$30^b \pm 3.2$
Lava Meal	$14.8^b \pm 0.5$	$208^c \pm 2.7$	$30^b \pm 1.7$

‡ Untreated manure; † Values in the same column with different letters as superscript differ significantly ($P < 0.05$)

CONCLUSIONS: The use of bedding additives not only reduced manure N losses during storage but also increased N use by the maize crop. Zeolite appeared the most effective bedding additive in this regard. From a cost perspective, it is concluded that sandy farm topsoil is the most attractive bedding additive to mitigate total NH_3-N and N_2O-N emissions, as well as total N losses, during manure storage and increases its fertiliser value after field application. Our results suggest that all the bedding additives have great potential for use in organic agriculture since they can improve the agro-environmental value of cattle straw manure.

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AMMONIA AND METHANE EMISSIONS. AFTER ON-FARM AEROBIC TREATMENT IN A PIG SLURRY LAGOON

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ABSTRACT: Slurry aeration is considered a CH_4 reduction technique as oxygen is introduced into the slurry and oxidizes organic matter into CO_2 and H_2O. Nitrogen (N) removal by aerobic treatments can achieve up to 70% of slurry N, but ammonia (NH_3) can be emitted during slurry aeration, which derives from the decomposition of urea in animal wastes. In this study, an on-farm experiment was performed to estimate NH_3 and CH_4 emissions from aerobic treated pig slurry storage. A slurry lagoon was aerobically treated and gas emissions were measured by a sampling system based on the dynamic chamber system. NH_3 and CH_4 emissions increased by 100% and 20%, respectively, at the beginning of the aeration. During the following aeration days, average CH_4 emissions were 78% lower, while there was no significant effect on NH_3 volatilization with respect to pre-aeration conditions. Urease activity was not affected by aeration treatment.

Keywords: ammonia, aeration, methane, slurry, storage

INTRODUCTION: Liquid manure storage facilities are sources of ammonia (NH_3) and methane (CH_4) emissions, which have achieved importance in animal production from the perspective of environmental and health protection (Webb et al., 2005). CH_4 is mainly produced from decomposition of manure under anaerobic conditions (Moss et al., 2000), especially when manure is stored in liquid form. Slurry aeration is considered a CH_4 reduction technique as oxygen is introduced into the slurry and oxidizes organic matter to CO_2 and H_2O. In the same way, nitrogen (N) removal by aerobic treatments can achieve up to 70% of slurry N through conversion in gaseous compounds by nitrification and denitrification processes (Beline et al., 1999; Loyon et al., 2007). However, NH_3 can be emitted during slurry aeration, which derives from the decomposition of urea in animal wastes (Van der Peet-Schwering et al., 1999). NH_3 is formed by the breakdown of urinary urea and is conducted by the urease enzyme of faeces. As result of urease activity, urea is converted into ammonium (NH_4^+) and NH_3 in a matter of hours to a few days following excretion (Beline et al., 1998). In this study, an on-farm experiment was performed to estimate NH_3 and CH_4 emissions from aerobic treated pig slurry storage.

1. MATERIAL AND METHODS: A farm-scale measurement trial was performed at a commercial pig-fattening farm in the Basque Country, Spain (42° 53′ 41″ N, 2° 44′ 16″ W). The slurry stored under the slatted floor in the building was regularly pumped to an outdoor lagoon (768 m^3) where an aerobic treatment was performed twice a day (one hour in the morning and one hour in the afternoon), from the 20th to 23rd of June 2011. The treatment consisted of intermittent aeration by a submerged ejector aerator combined with a mixer (Fig.1). Following morning aeration, NH_3 and CH_4 emissions from the lagoon were measured using a sampling system based on the dynamic chamber system (Peu et al., 1999) (Fig.2a). Samples were determined *in situ* by a Bruel & Kjaer 1302 photoacoustic analyzer during 5 hours each day, with a daily frequency (Fig.2b). Three emission data registered from chambers during the 5 hours were statistically analyzed with the Statistical Package for the Social Sciences 15.0 (SPSS Inc.). Data were analyzed as repeated measures according to emissions'

evolution during measuring days. Significant differences are expressed at $P<0.05$, unless otherwise stated.

Slurry was analyzed for dry matter content (DM), total N (TN), ammonium-N (NH_4^+-N) and urease activity.

Figure 1. Aeration treatment on pig slurry storage.

Figure 2. (a) dynamic chamber gas sampling system and (b) in situ gas monitoring unit.

2. RESULTS AND DISCUSSION: On the first aeration day, NH_3 and CH_4 emissions increased by 100% and 20%, respectively, with respect to averaged volatilization from the previous days (Fig.3). The NH_3 result coincided with those from Amon et al. (2006), who observed that slurry aeration nearly doubled NH_3 emissions compared to untreated slurry. Over the following days, under optimal climatic conditions for NH_3 volatilization (warm temperature and no rainfall), NH_3 emissions decreased an average of 40.4% from day to day. Average CH_4 emissions from the second aeration day up to the end of experiment were 78% lower than those from the first aeration day.

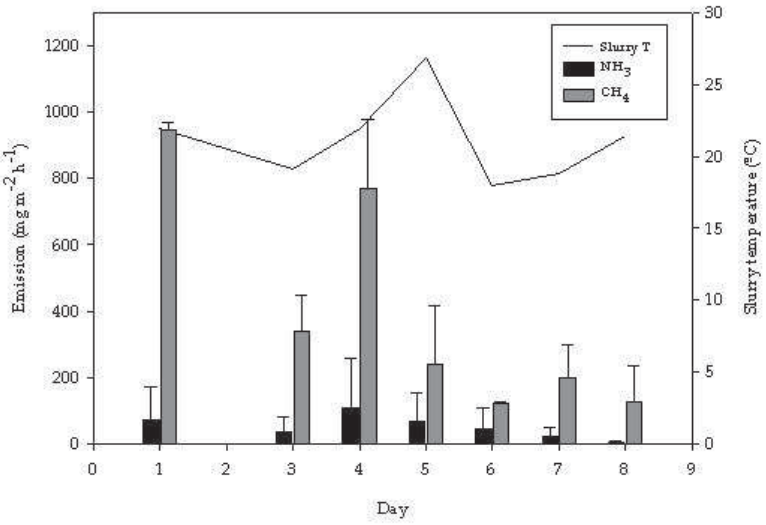

Figure 3. Pattern of daily NH_3 and CH_4 emissions (mg m^{-2} h^{-1}) during 5 hours and air temperature (ºC). Aeration was carried out on days pointed by arrows.

During the study, NH_4^+-N concentration in slurry did not change (Table 1), probably because several processes were taking place simultaneously, such as mineralization, ammonification, nitrification and NH_3 volatilization.

Table 1. Slurry characterization.

Parameters	Before aeration treatment (d 1)	After first aeration (d 4)	After aeration treatment (d 8)
DM (%)	6.57	10.01	9.80
TN (g/L)	7.67	7.87	8.75
NH_4^+-N (g/L)	5.53	5.21	5.74

Table 2 shows the mean urease activities during the experimental period, which were similar to data reported by Ros et al. (2006) for pig slurry.

Table 2. Mean urease activity (µmol NH_4^+-N g^{-1} h^{-1}) of pig slurry before and after aerobic treatment (mean ± sd).

	Urease activity (µmol NH_4^+-N g^{-1} h^{-1})
Before aeration	0.19 ± 0.24
After third aeration day (day 6)	0.26 ± 0.01

In comparison to average NH_4^+-N concentrations presented in slurry (5.06 g NH_4^+-N kg^{-1} slurry h^{-1}), there was little production of NH_4^+-N (low urease activity) during the study. Additionally, NH_4^+-N production represented 0.09% of NH_4^+-N content in the slurry. Urease activity showed high variability during the study and was not affected by aeration treatment.

CONCLUSION: NH_3 and CH_4 emissions increased by 100% and 20%, respectively, on the first aeration day. During the following aeration days, average CH_4 emissions were 78% lower than those from the first aeration day, while there was no significant effect on NH_3 volatilization with respect to pre-aeration conditions.

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AGRICULTURAL GREENHOUSE GAS EMISSIONS REDUCED BY AGRI-ENVIRONMENT SCHEMES ON IMPROVED GRASSLAND GRAZED BY INTENSIVE BEEF CATTLE

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ABSTRACT: The alteration of land use and management practices under agri-environment schemes may impact agricultural greenhouse gas emissions. Scheme agreements require modifications to, for example, the location of livestock during the winter or stipulate the targeted creation of grass buffer strips to reduce erosion. The following paper reports on the change in net greenhouse gas emissions for agri-environment schemes applicable to intensive beef production, relative to existing land management. A life cycle assessment approach has quantified the net greenhouse gas emissions, either positive or negative, that result from a change in management as stipulated by the agri-environment scheme agreement. Seasonal livestock removal (winter housing) reduced emissions, mainly nitrous oxide, from wet and potentially compacted soil and prevented soil carbon loss, typically by a net of -0.1 t CO_2eq ha^{-1} $year^{-1}$. The method of manure storage during the housing period is potentially key in defining the overall impact. Strategies to mitigate emissions during storage, for example the covering of lagoons, are essential to maximise the value of seasonal livestock removal in reducing greenhouse gas emissions. The creation of grass buffer strips had the greatest potential to reduce emissions overall, particularly when placed adjacent to watercourses to prevent erosion or run-off (-11.6 t CO_2eq ha^{-1} $year^{-1}$). They require, however, the removal of land from its current management. Careful targeting of these options is critical to maximise agricultural greenhouse emissions reduction from Environmental Stewardship and to minimise the risk of agricultural production displacement.

Keywords: GHG, N_2O, CH_4, cattle, agri-environment scheme

INTRODUCTION: Agri-environment schemes, such as Environmental Stewardship (ES), were introduced in England in response to reform of the Common Agricultural Policy (CAP). Scheme objectives are: to improve water quality and reduce soil erosion, enhance farmland wildlife, maintain and enhance landscape character, and protect the historic environment (Natural England, 2010ab). The landowner receives payment to compensate for income foregone (such as a reduction in or loss of crop yield, or increased management costs) associated with any required change in land use and land management, to a maximum of 100%. The specified management changes may also impact agricultural greenhouse gas (GHG) emissions and climate change mitigation, on which this paper reports for ES options relevant to intensive beef production.

1. MATERIAL AND METHODS:

1.1. Boundary, baseline setting and management modifications for ES options: A baseline management scenario provides a reference point against which changes in land use or land management practices, through the implementation of ES agreements, can be compared. The temporary grassland grazed by intensive beef cattle (TGBC) baseline and ES option management scenarios (Natural England, 2010ab) are summarized in Table 1. Options that stipulate existing minimum nitrogen

(N) fertilizer inputs (EE6, EE10, HJ6) are implemented where the majority of N is supplied by inorganic fertilizer (TGBC). Other options (EK1, HE11) assume a proportion of N is supplied by clover (TGBC + clover). Livestock removal during the winter (HJ7) assumes cattle are grazed all year (TGBC clover + 100% grazing).

Table 1. Baseline temporary grassland grazed by beef cattle (TGBC) scenarios and Environmental Stewardship option management per ha per year.

Scenario	Lime (t)	Re-seed	N (kg)	P_2O_5 (kg)	Chain harrow	Mow / herbicide[a]	Head	Housed[b]
Baseline								
TGBC	0.75	0.2	210	20	1	0 / 1	2.8	Yes
TGBC + clover	0.75	0.2	100	20	1	0 / 1	2.8	Yes
TGBC + clover + 100% grazing	0.75	0.2	100	20	1	0 / 1	2.8	0
ES option								
EE6 / EE10 / EK1 - Buffer strips & Field corners	0	0	0	0	0	2 / 1	0	0
HJ6 - Erosion or run-off prevention	0.75	0.2	100	20	1	0 / 1	1.2	Yes
HJ7 - Seasonal stock removal	0.75	0.2	100	20	1	0 / 1	2.8	Yes
HE11 - Enhanced buffer strips	0	0	0	0	0	1 / 0	0	0

[a]Herbicide (fluroxypyr 200 g l^{-1}) applied by weedwiper; [b]Feed as concentrates (495 kg per head) and silage (1571 kg DM per head)

The total N excreted by cattle per ha per year are compliant with Nitrate Vulnerable Zone rules of 170 kg N ha^{-1} annual farm limit and 250 kg N ha^{-1} annual field limit (Defra, 2009). The required feed (to satisfy total metabolisable energy need) and composition (proportion of concentrates, grass silage and grazing) have been derived from Defra (2010) and Williams et al. (2009). Manures are stored as farmyard manure in unconfined piles or stacks at a mean temperature of less than 10^{o}C (assumed to be stored during the winter for application during the spring).

1.2. Inventory of greenhouse gas emissions:

1.2.1. Nitrous oxide: Nitrous oxide is emitted post application from inorganic nitrogen fertilizer and manures, manures during storage and from livestock deposition (IPCC, 2006; Williams et al., 2009). Four processes are involved: microbial nitrification and denitrification, nitrate (NO_3^-) leaching and ammonia (NH_3) volatilization. The IPCC (2006) methodology to calculate N_2O from the application of inorganic or organic N to grassland in northern Europe has been followed. Housing livestock during the winter replaces direct N deposition onto grass with N collected and stored as manure. The quantity of N_2O emitted per kg of N excreted depends on the storage method and duration (IPCC, 2006; Williams et al., 2009). Nitrous oxide emissions have been calculated per kg of N excreted for the stocking rates stated in Table 1, annual N excretion values per head of beef cattle (Defra, 2009), and method (grazing or manure piles), split proportionally for an assumed 151 days of housing.

1.2.2. Methane: Feed digestion by beef cattle emits CH_4 (IPCC, 2006). The calculated enteric CH_4 emission is accounted for by the proportion of forage relative

to concentrates in the diet (Williams et al. 2009). Estimation of methane produced from manure during housing considers the volatile solids within the feed consumed (Thomas, 2004), storage method and storage temperature (IPCC, 2006).

1.2.3. Carbon dioxide: Fossil fuel consumption during the operation of agricultural machinery or during the manufacture of agro-chemicals emits CO_2. The calculations incorporate direct Scope 1 emissions (spraying, spreading and tillage) and indirect Scope 3 emissions (manufacture of pesticides, fertilizers and farm machinery (Brentrup and Pallière, 2008; Tzilivakis et al., 2005; Williams et al., 2009).

2. RESULTS AND DISCUSSION: Input free grass strips (EE6) reduce GHG emissions by an estimated 11.5 t CO_2eq ha^{-1} $year^{-1}$ relative to the TGBC baseline (Figure 1).

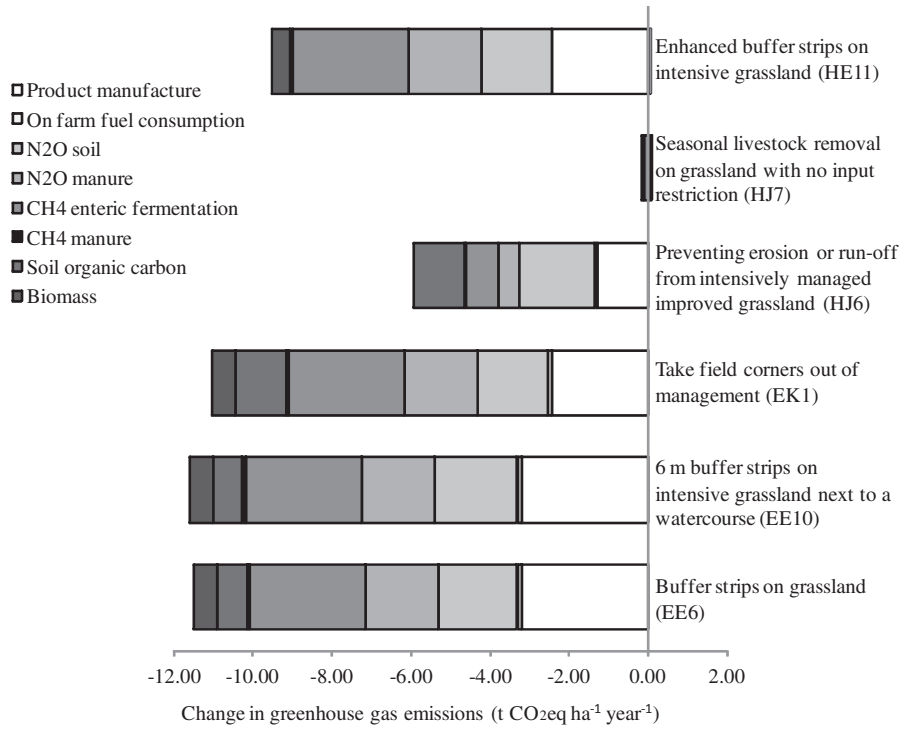

Figure 1. Baseline scenario greenhouse emissions (t CO_2eq ha^{-1}) and impact of ES options on emissions EDP and as mitigation.

Where buffer strips prevent erosion or surface run-off entering a watercourse (EE10), the utilisation by grass of the NO_3^- within the run-off captured by the buffer strip, further reduces indirect N_2O emission (-11.6 tCO_2eq ha^{-1} $year^{-1}$). Option HJ6 does not remove livestock completely. Erosion or run-off is prevented by a reduction in stocking rate and N fertilizer. The appropriate spatial targeting of these options confers an additional GHG reduction capacity to the reductions associated solely from the removal of livestock and reduction of agro-chemical inputs.

Livestock may congregate in particular areas of a field (e.g. near gateways or feeders) and cause poaching, topsoil compaction and hinder grass growth. Poaching and compaction create anaerobic soil conditions (Moorby *et al*., 2007) that favour denitrification (Machefert *et al*., 2002), exacerbated in combination with the

concentration of deposited N. Seasonal livestock removal on grassland with no input restriction (option HJ7) has potential to reduce topsoil structural damage and N deposition onto wet soils, where the risk of NO_3^- leaching and surface run-off, or soil compaction and denitrification, are greater. There is potential for 'pollution swapping', when, for example, increased CH_4 emission from manure storage compared to direct deposition onto grassland (IPCC, 2006). As such, the method of manure storage is critical in maximising the benefit of ES options that remove livestock from grazing land during the winter.

CONCLUSION: The removal of productive grassland from production risks the displacement of that production elsewhere, and no net emissions reduction may result. The spatial targeting of ES options to prevent erosion or run-off into water courses, or removal of livestock from land during the winter where compaction and increased denitrification is a risk, provides additional GHG reduction benefits beyond the removal of land from production alone.

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DOES IMMEDIATE INCORPORATION OF SOLID MANURES TO REDUCE AMMONIA EMISSIONS INCREASE EMISSIONS OF NITROUS OXIDE?

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ABSTRACT: Few studies have measured the effects of rapid incorporation of solid manures on both ammonia (NH_3) and nitrous oxide (N_2O) emissions in the field. The objectives of this study were to measure the effects of immediate incorporation of solid manures by inversion and non-inversion cultivation techniques on NH_3 and N_2O emissions. We applied four types of solid manure, cattle farmyard manure (FYM), pig FYM, layer manure and broiler manure by four methods: surface application and immediate incorporation by plough, disc or spring tine.

There were 4 replicates of each treatment in 8 field experiments. A control plot in each randomised block provided measurements of background emissions of N_2O, giving 17 plots per block with treatments applied to each block in successive weeks. Emissions of NH_3-N and N_2O-N from each experiment as kg N/ha, % N (N_2O), % TAN (NH_3) and % abatement by the incorporation treatments, were subject to analysis of variance.

Incorporation with either disc (*c*. 60% abatement) or tine (*c*. 50% abatement) was significantly less ($P < 0.05$) effective in reducing NH_3 emissions than incorporation by plough (*c*. 90% abatement) compared with no incorporation.

The effect of incorporation on direct N_2O emissions was inconsistent. At some sites there were significant increases, and at other sites significant decreases, in N_2O emissions following incorporation by plough. Generally incorporation by disc and time had little effect on N_2O emissions.

The results indicate that incorporation of solid manures to reduce NH_3 emissions does not always lead to increased emissions of N_2O.

Keywords: N_2O, manure, rapid incorporation, mitigation strategy, NH_3.

INTRODUCTION: Previous work suggests that while injection of liquid slurries to reduce emissions of ammonia (NH_3) may either increase or have no impact on emissions of nitrous oxide (N_2O), incorporation of litter-based farmyard manures (FYM) appears to reduce or have no impact on N_2O emissions (Webb et al., 2010, and references cited therein). The addition of readily-metabolizable C in slurry has been proposed as a mechanism for increasing emissions of N_2O by more than would be expected due to the additional N entering the soil as a result of NH_3 abatement. In contrast, there is evidence that readily-degradable C is lost as part of the effluent arising during storage of solid manures. However, the findings of Webb et al. (2010) were based on limited data since few studies have reported the interaction between rapid incorporation of solid manures to reduce emissions of NH_3 on subsequent emissions of N_2O.

1. MATERIAL AND METHODS: Between February 2003 and October 2006, 8 experiments were carried out to measure the impact of immediate incorporation of solid manures on emissions of NH_3 and N_2O. The experiment used four types of solid

manure, cattle FYM, pig FYM, layer manure and broiler litter. The four incorporation treatments were as follows:

1. Manure left on surface.

2. Immediate incorporation by plough.

3. Immediate incorporation by disc.

4. Immediate incorporation by spring tine.

There was an additional control plot in each block to provide estimates of background emissions of N_2O, giving a total of 17 plots per block in a randomised block design. Each of the 17 treatments was replicated four times with treatments applied to each block in successive weeks (to allow efficient use of resources, e.g. ammonia wind tunnels) (Webb et al., 2006). Samples of manure were taken from each plot and analysed for % dry matter, total-C, total-N and total ammoniacal-N (TAN). Ammonia emissions were measured for up to 2 weeks after manure application, using wind tunnels (one per plot) based on the design of Lockyer (1984). Direct N_2O measurements were made using 2 static chambers (0.32 m^2 total surface area) per plot and analysed using gas chromatography. Measurements were carried out immediately following manure application and at regular intervals over a *c*. 60-day period. Six of the eight experiments were continued over a 12-month measurement period.

The NH_3-N and N_2O-N emissions from each experiment were expressed as kg N/ha, % of total N applied (N_2O) and % of total TAN applied (NH_3). The NH_3 abatement efficiency was also determined as the mean reduction in emission achieved by the incorporation technique divided by the mean emission measured from the manure left on the soil surface. All data were subject to analysis of variance after a Michaelis-Menten function was fitted to the NH_3 measurements from each plot.

2. RESULTS AND DISCUSSION:

2.1. Ammonia emissions: Ammonia emissions are summarised in Table 2 for each experiment to indicate significant differences within each experiment. Since the amounts of TAN differed widely among manures, the abatement efficiencies of each incorporation technique are better expressed as % abatement compared with unincorporated manures.

Table 1. Results of analysis of variance of ammonia emissions measured in each experiment, %TAN.

Experiment	Incorporation method	Manure type	Interaction, incorp/manure
1 [GL03]	P < 0.001	P = 0.064	P = 0.067
2 [DT03]	P < 0.001	P < 0.001	P = 0.044
3 [IG03]	Data could not be reported because of equipment failure		
4 [GL04]	P < 0.001	P = 0.022	NS
5 [IG04]	P < 0.001	NS	NS
6 [DT05]	P < 0.001	P < 0.003	P = 0.015
7 [IG05]	P < 0.001	P < 0.001	P = 0.017
8 [IG06]	P < 0.001	P < 0.001	NS

Table 2. Results of cross site analysis of variance of ammonia emissions measured in each experiment, % abatement.

Site	Manure	Plough	Disc	Tine
Mean	Cattle	[a]94	[b]40	[b]51
	Pig	[a]88	[b]65	[b]51
	Layer	[a]91	[b]69	[c]40
	Broiler	[a]89	[a]76	[a]71
	Mean	[a]90	[b]62	[b]53
	SED, cultivation	5.5		
	SED, cultivation/manure	11.1		

Estimates prefixed by the same letter are not significantly different (P < 0.05)

On average, immediate incorporation by plough reduced NH_3 emissions by *c*. 90% compared with no incorporation. The efficacy of ploughing was consistent among all 4 manures. Although emissions were also reduced by incorporation with either disc or tine the efficacy was much less than for incorporation by plough, although not significantly so for broiler manure. In most cases there was no significant difference in abatement between disc and tine. The abatement achieved by non-inversion techniques was variable and suggests that, for solid manures, incorporation by plough is not only more effective on average but also a more consistent means of reducing NH_3 emissions.

2.2. Nitrous oxide emissions:

Table 3. The effect of incorporation on the mean c. 60-day cumulative N_2O-N loss expressed as a % of the total manure N applied per experiment.

Site	P Treatment	Surface	Plough	Disc	Tine	Daily rainfall (mm)
1 - GL03	P = 0.001	0.36	1.39	0.44	0.45	0.1
2 - DT03	NS	0.04	0.01	0.03	0.03	0.5
3 - IGL03	NS	0.34	0.47	0.55	0.52	<0.1
4 - GL04	P = 0.001	0.31	1.22	0.73	0.43	0.8
5 - IGL04	P = 0.066	1.44	0.54	1.75	1.62	0.1
6 - DT05	P = 0.004	0.07	0.04	0.06	0.02	<0.1
7 - IGH05	P = 0.006	0.07	-1.00	0.23	0.23	<0.1
8 - IGH06	NS	1.07	0.79	0.96	0.87	

*rainfall in the 5 weeks following the first manure application

Although the effect of incorporation on N_2O emissions was significant at 5 of the sites, direction of the effect differed, increasing emissions at sites 1 and 4 but decreasing them at sites 5, 6 and 8. It might be assumed that at sites at which denitrification was likely to be the dominant source of N_2O emission (high average annual rainfall and/or heavy soil texture), ploughing would reduce N_2O emissions due to the increased length of the N_2O diffusion pathway. This was the case at DT in 2005 and at the two IG sites on heavy soil. However, at DT in 2003 there was no effect of cultivation on N_2O emissions, while ploughing reduced N_2O emissions on the light IG site in 2004. However, there was also an interaction with rainfall in the 4-6 weeks after the first manure application. Three of the four sites at which ploughing reduced N_2O emissions were either dry or very dry (as were the two sites where there were no significant effects of incorporation. The only two sites at which there was appreciable rainfall following manure application were those at which incorporation increased

N_2O emissions, suggesting that there was greater production of N_2O by nitrification of conserved NH_4.

CONCLUSION: Immediate incorporation of solid manures reduced NH_3 emissions by up to 90%. The effects of incorporation on N_2O emissions were inconsistent, with rainfall in the period following application appearing to have a major influence.

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DUST FILTERING PROPERTIES AND AMMONIA EMISSION OF ON-FARM DRYING SYSTEMS FOR POULTRY MANURE

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ABSTRACT: In the Netherlands, measures for mitigation of Particulate Matter (PM) emissions are needed for poultry houses to lower their contribution to elevated ambient PM concentrations. In this study, we 1) investigated whether on-farm drying systems (DS) for poultry manure can remove PM from the exhaust air flow, and 2) evaluated the contribution of DS to ammonia emissions. At two layer facilities, a total of twelve 24-hour measurements were carried out of temperature, relative humidity, ventilation rate, PM and ammonia between December 2009 and February 2010. A substantial removal of inhalable dust (69% for house 1), PM_{10} (83% for house 1; 33% for house 2) and $PM_{2.5}$ (57% for house 1; 32% for house 2) was found. Concentrations of ammonia however, increased by a factor 5.0 (house 1) and 3.6 (house 2) over the manure layer. This study shows that DS for poultry manure show good ability to remove PM, but further research is necessary to avoid problem swapping by elevating emissions of other pollutants.

Keywords: poultry, manure drying systems, particulate matter, ammonia, abatement

INTRODUCTION: Elevated concentrations of particulate matter (PM) in the ambient air are considered a public health risk (Heederik et al., 2011). PM emissions from animal houses contribute significantly to ambient PM concentrations in the Netherlands (CBS et al., 2009). Measures are needed to mitigate animal house PM emissions to comply with PM limits in ambient air set in EU Directive 2008/50/EC (Annex XI). A practical measure to reduce PM emissions from poultry houses may be the dual use of poultry manure drying systems (DS) for both manure drying and dust filtration. In the Netherlands, DS are mainly applied at hen-rearing and laying facilities for drying fresh or pre-dried droppings to >80% of dry matter (DM) within 48-96 h. After drying, manure is transported to arable farms, biomass power plants or fertilizer producers. Inside these poultry facilities, hens deposit their manure on belts (underneath cages, raised slatted floors or wired floors in aviary systems), and manure is frequently transported to the DS, usually located in a separate space next to the house. Depending on the type and sizing, the DS is usually composed of 2-12 vertical tiered perforated polypropylene or metal belts. The manure is spread in a layer of 3-15 cm onto the uppermost belt. Drying is done by forcing warm exhaust air through the manure layers by means of pressure fans that maintain overpressure in a pressure corridor between the house and the DS. Usually, the minimum required house ventilation (1-2 m^3 h^{-1} $bird^{-1}$) is used for drying, and any extra ventilation is released through bypass fans, directly to the outside air. When manure reaches the end of a belt, it falls down onto the next belt below, until it finally reaches the end of the lowermost belt, after which the dry manure is further transported to storage. In earlier research on similar DS, some extra ammonia emission was found, but PM concentrations were not determined (Groot Koerkamp and Montsma, 1995, Huis in 't Veld et al., 1999). In this study, we 1) investigated whether on-farm DS for poultry manure can remove PM from the exhaust air flow, and 2) evaluated the contribution of DS to ammonia emissions.

1. MATERIAL AND METHODS:

1.1. General design of the study: The study was done at two commercial laying facilities in the Netherlands. A description is given in Table 1. At these locations, we carried out in simplo measurements of temperature and relative humidity, and duplicate measurements of CO_2 (calculation of ventilation rate), PM (inhalable dust, PM_{10}, and $PM_{2.5}$), and ammonia, both upstream (pressure corridor) and downstream of the DS. Six 24-hour measurements were done per house between December 2009 and February 2010.

Table 1. Characteristics of the layer houses and drying systems.

	House 1	House 2
Type of housing	2-story house; aviaries	2 houses; cages
Manure belt aeration	Not present	1 house; 0.7 m^3 h^{-1} $bird^{-1}$
Ventilation type	Side wall inlets; end wall fans	Belt aeration + side wall inlets; side wall fans
Number of hens	65,000	76,800 + 49,600
Type of drying system	Metal belts	Polypropylene belts
Drying levels (belts)	1 System of 4 levels	2 Systems of 10 levels
Belt dimensions (m)	18.5 x 2	40 x 1.5
Layer thickness (cm)	15–20	9
Max. drying vent. (m^3 h^{-1} $bird^{-1}$)	2.1	2.4
Max. bypass vent. (m^3 h^{-1} $bird^{-1}$)	3.9	3.6
Manure loading	Every 12 hours	Every 24 hours
Manure drying time	4 days	5 days

1.2. Temperature, relative humidity and ventilation rate: Temperature and relative humidity were measured continuously with combined sensors (Rotronic; ROTRONIC Instrument Corp., Huntington, NY, USA) and data were stored in a data logging system. A 24-hour average air sample was taken using the lung principle (40 L Nalophan air sampling bags, sampling at 0.02 L min-1) and analysed for CO_2 concentration by gas chromatography (Interscience/Carbo Erba Instruments, GC 8000 Top) to determine ventilation rate using the CO_2 mass-balance method (Pedersen et al., 2008, CIGR, 2002).

1.3. Particulate Matter: Inhalable dust was sampled using IOM samplers (at 2 L min-1; SKC Inc., Eighty Four, PA, USA), following EN 481. PM_{10} and $PM_{2.5}$ were sampled using cyclone pre-separators (URG corp., Chapel Hill, NC, USA), glass fibre filters (type MN GF-3, Ø 47 mm, Macherey-Nagel GmbH & Co., Düren, Germany) and sampling pumps (at 1 m^3 h^{-1}; Ravebo Supply BV, Brielle, the Netherlands), following CEN-EN 12341 for PM_{10} and CEN-EN 14907 for $PM_{2.5}$. For more details on the sampling procedure, see Zhao et al. (2009).

1.4. Ammonia: Ammonia was collected using acid traps (critical capillary of 1 L min^{-1}; impingers with 100 ml of nitric-acid solution at 0.05 M), and ammonia content was determined by spectrophotometry.

2. RESULTS AND DISCUSSION: Main results of measurements are summarised in Table 2. In both DS, the air humidity increased to levels above 90% accompanied by a drop in air temperature of 3-5 °C, in agreement with earlier studies on similar systems (Groot Koerkamp and Montsma, 1995, Huis in 't Veld et al., 1999). This represents

the evaporation of water from the manure into the gas phase, which requires the input of thermal energy. Because of the low outside temperatures in winter, DS ventilation was sufficient to maintain the target house temperature during 11 of 12 measurements, when no extra bypass ventilation occurred.

Table 2. Mean values (± SD) of upstream and downstream measurements.

	House 1 (*n*=6)		House 2 (*n*=6)	
	Upstream	Downstream	Upstream	Downstream
Air temperature (°C)	17.1 ± 0.6	12.8 ± 1.0	20.4 ± 1.4	17.6 ± 0.8
Relative humidity (%)	65.1 ± 3.4	97.7 ± 4.4	70.8 ± 7.2	90.6 ± 6.2
Vent. rate (m^3 h^{-1} $bird^{-1}$)	1.7 ± 0.6		1.4 ± 0.6	
Inhalable dust (mg m^{-3})	5.00 ± 0.66	1.66 ± 1.63	not determined	
PM_{10} (mg m^{-3})	2.58 ± 0.37	0.42 ± 0.07	0.42 ± 0.04	0.28 ± 0.02
$PM_{2.5}$ (mg m^{-3})	0.17 ± 0.05	0.07 ± 0.02	0.03 ± 0.01	0.02 ± 0.01
NH_3 (ppm)	4.3 ± 0.9	23.8 ± 15.7	14.6 ± 3.5	48.7 ± 5.4

Concentrations of the three PM fractions were all reduced over the manure layer. For inhalable dust (only house 1), mean reduction (± SD) was 69 ± 27%. Mean PM_{10} reductions (± SD) were 83 ± 5% for house 1 and 33 ± 3% for house 2. Mean $PM_{2.5}$ reductions (± SD) were 57 ± 18% for house 1 and 32 ± 12% for house 2. Both PM_{10} and $PM_{2.5}$ reductions were generally higher for the DS of house 1, which may be due to the larger layer thickness, resulting in a longer air residence time, and greater chance for particles to be captured in the pores between the sticky droppings.

For ammonia, substantial extra emission occurred from the manure layer. On average, the ammonia concentration increased by a factor 5.0 for house 1 and 3.6 for house 2. A previous study of a similar drying system attached to an aviary house, however, reported a mean extra ammonia emission of only 2 g $year^{-1}$ animal $place^{-1}$ on top of a house emission of 96 g $year^{-1}$ animal $place^{-1}$ (Huis in 't Veld et al., 1999). But also in this study, ammonia concentrations increased when passing the manure layer. Mean ammonia concentrations were 3 ppm upstream and 6 ppm downstream of the DS (increase by a factor of 2) in winter, whereas in summer, mean concentrations were 16 ppm upstream and 18 ppm downstream (increase by a factor of 1.3). Due to the low drying ventilation rate (0.14 m^3 h^{-1} $bird^{-1}$ versus 9.3 m^3 h^{-1} $bird^{-1}$ of bypass ventilation capacity), small extra emissions were reported. In the current DS designs however, much higher drying ventilation rates are applied, probably causing active stripping of ammonia from the manure (Groot Koerkamp, 1994). Further research is necessary to identify effective measures to avoid this. Reducing the time between deposition of fresh manure and transport to the DS, followed by more rapid drying (e.g. >60% of DM within 24 h), may be one such measure (Groot Koerkamp and Montsma, 1995).

CONCLUSION: This study shows that DS for poultry manure show good abilities to remove PM, but further research is necessary to avoid problem swapping by elevating emissions of other pollutants.

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Part IV
Modeling

A DYNAMIC MODEL OF AMMONIA EMISSION AND CONCENTRATION IN FATTENING PIG BUILDINGS

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ABSTRACT: The control of gas emissions from livestock buildings, especially ammonia, is important to limit the environmental impact, which depends primarily on the cumulated emission, and to improve the welfare and health of the animals and the stockmen, are affected by gas concentration inside the building. The model developed in this work aims at integrating the information and models already available in the literature in order to predict the ammonia emission and concentration inside the fattening rooms and in the exhausted air. The model includes the description of animals and feeding, housing and indoor climate, and processes involved in ammonia emission. Different housing designs are considered in the model including different types of slatted floors and ventilation systems. The effect of outdoor climate, including seasonal and diurnal variations, is also taken into account. The model predicts the indoor climate and the emission and concentration of ammonia. A sensitivity analysis has been performed in order to evaluate the effects of season, type of ventilation, and type and cleanliness of floor. These simulations indicated that ammonia emission and concentration are not well correlated and are highly dependant on the ventilation system and the temperature. The model was validated by comparison with ammonia concentration available from the literature, with different types of ventilation and slatted floor, and different indoor temperatures.

Keywords: ammonia, modelling, effluent, housing, swine

INTRODUCTION: The reduction of ammonia emissions from pig buildings is important because of the negative impact of this gas on the environment. These emissions contribute to acidification, eutrophication and the loss of biodiversity (Sutton et al., 2011). Moreover, high ammonia concentrations in pig buildings have adverse effects on animal's health and performance, and on health and wellbeing of stockmen (Portejoie et al., 2002). Ammonia emissions have also a major contribution to the formation of secondary small particulate matter which has been linked to public health issues in regions with high animal density (Sheppard et al., 2009).

In conventional piggeries for fattening pigs with storage of the slurry in a pit under a slatted floor, ammonia-N emission amounts 20 to 25% of total N excreted, corresponding to about 10 g/d per pig (Griffing et al., 2007; Rigolot et al., 2010). However, the level of these emissions varies widely according to different factors of variation including animal feeding and performance, type of floor, slurry handling, and ambient temperature and ventilation (Rigolot et al., 2010).

In this context the objective of the present work was to build a model for fattening pigs which predicts the effects of these different variation factors on ammonia emission toward the environment as well as its concentration in the building.

1. MATERIAL AND METHODS:

The model is composed with three modules representing (i) the animals, including feeding, growth, heat production, excretion, (ii) the building with indoor climate, and (iii) ammonia concentration and emission. These modules were partially built on the basis of already existing models (Aarnink et al., 1998; Schauberger et al., 2000; Rigolot et al., 2010a,b). Ambient temperature is calculated from the room enthalpy and depends on animal heat production, heat losses through the walls, floor and ceiling, outdoor temperature, ventilation rate, and possibly on heating (figure 1a). Ventilation rate is automatically regulated by the model according to a target ambient temperature, as in commercial conditions.

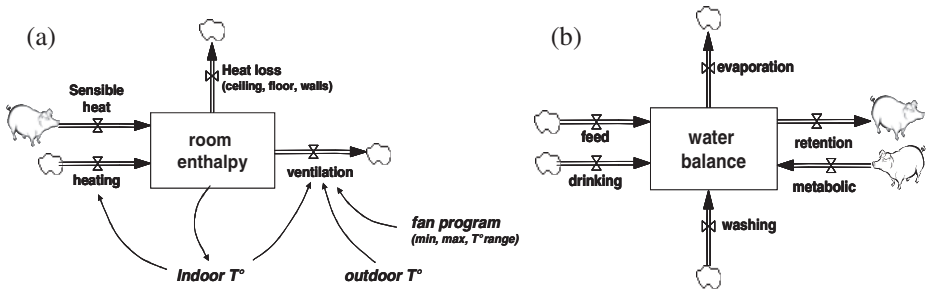

Figure 1. Modelling of heat exchanges, ventilation, temperature and water balance.

Animal's excretion and heat production are determined according to their performance, and the composition of the feed (Rigolot et al., 2010a). Heat production is partitioned among sensible and latent heat according ambient temperature (GIGR, 1984). Water balance is calculated considering water intake, evaporation, retention by the pigs and production by the metabolism, and water used for cleaning (Figure 1b).

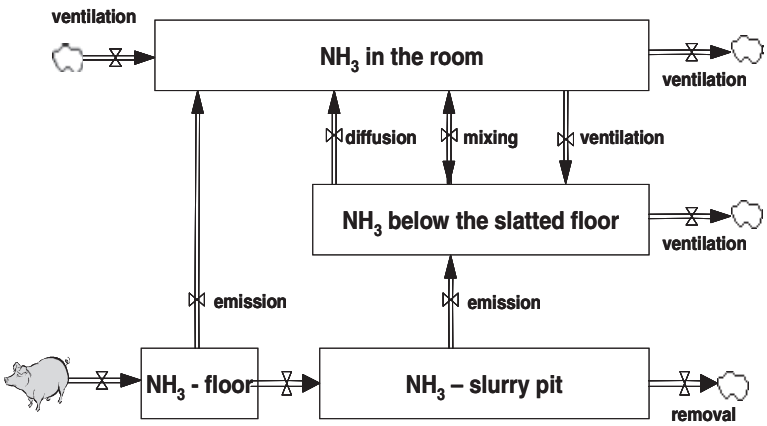

Figure 2. Modelling of ammonia emission and concentration.

Ammonia is present in four compartments: excreta on the floor, slurry in the pit, in the air below the slatted floor, and in the air of the room (Figure 2). In liquid compartments ammonia is present in the form of ammonium (NH_4^+) and dissolved or gaseous ammonia (NH_3). The chemical equilibriums between these different forms are represented in the model as well as the effects of slurry pH and temperature. Ammonia volatilisation depends on slurry gaseous NH_3 concentration, slurry temperature and air velocity. The model was built using Vensim® modelling platform

with a time step of one minute. Different types of housing were considered with different floors (total or partial slatted floor), different locations of air extraction (under the slatted floor, in the room). A note of floor cleanliness was also considered in order to estimate the amount of excreta remaining on the floor.

2. RESULTS AND DISCUSSION:

2.1. Simulation and validation: The model was used to simulate the effect of slatted floor type (total, partial), season (summer, winter), and location of air extraction (under the floor, in the room) on average NH_3 concentration in the room and total emission during the fattening period. The main results are presented in table 1. With totally slatted floor, the highest emission (1.05 kg N-NH_3/pig) is obtained during summer for an under-the-floor air extraction, whereas in that situation NH_3 concentration in the room is the lowest (4 ppm). Conversely, during winter with in-the-room air extraction, total NH_3 emission is the lowest (0.54 kg N-NH_3/pig) and NH_3 concentration the highest (22 ppm). For the same rate of air renewal the in-the-room air extraction resulted in a higher NH_3 concentration and a lower emission, the ammonia emitted from the slurry pit being transferred through the room before being exhausted. When it was clean, the use of partial slatted floor resulted in lower NH_3 emission compared to totally slatted floor, because of the reduction of the pit emitting surface. This was not the case when the concrete area was dirty. NH_3 concentration was always higher with partial slatted floor because of the increased proportion of NH_3 being emitted from the floor for this system. These different results indicate that total ammonia emission and concentration may be not well correlated and are highly dependant on the ventilation system and the temperature.

Table 1. Simulation of the effect of type of slatted floor (total or partial), of season and localisation of air extraction (under-the-floor, in-the-room) on ammonia emission (kg N-NH_3/pig) and ammonia concentration (ppm)[1].

Season & air extraction	Totally slatted		Partially slatted			
			Dirty		Clean	
Summer						
under -the-floor	1.05	(3.5)	1.10	(7.1)	0.91	(6.0)
in-the-room	0.94	(14.0)	1.03	(15.7)	0.85	(13.2)
Winter						
under -the-floor	0.64	(7.9)	0.68	(15.0)	0.57	(12.6)
in-the-room	0.54	(22.1)	0.67	(28.0)	0.56	(23.6)

[1] *concentration between brackets (ppm)*

The model was validated by comparing model predictions with experimental results. Many studies were available for amounts of slurry and its N content and the comparison showed that they were well predicted by the model (r=0.95 and 0.77, respectively). Much less literature data were available for NH_3 concentration and emission. The effects of ventilation rate and type of floor on NH_3 concentration in the room were in agreement with the study of Guingand et al. (2001) and the effect of ambient temperature on NH_3 concentration below the stated floor or in the room was in agreement with Granier et al. (1996).

CONCLUSION: The proposed model allows predicting in a coherent way the cumulated ammonia flow and ammonia concentration. However, some lacks in knowledge were identified, in particular concerning the estimate of the pH of the liquid manure and the qualification of the floor's dirtiness. Likewise, it appeared that the air transfer between the air located above and below the slats must also be better

specified, because it strongly influences ammonia concentration in the room. The results from the simulations indicated that total ammonia emission and concentration may be not well correlated and are highly dependant on the ventilation system and the temperature. Thus, in practice, there may be some antagonism between the reduction ammonia emission and the improvement of air quality inside the building. The proposed model should contribute to identify optimal practices and techniques to reach the best compromises between these two objectives.

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A COMPARISON OF CARBON ACCOUNTING TOOLS AND AN EVALUATION OF THEIR POTENTIAL FOR GREENHOUSE GAS MITIGATION

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ABSTRACT: Animal agriculture (particularly that associated with ruminant livestock) plays a significant role in the emission of anthropogenic greenhouse gases, and as a result the industry is likely to remain under considerable pressure to improve its performance. Not least because of increasing demand for livestock products worldwide. However, although there are a number of options available for mitigating such emissions in the sector, their level of appropriateness varies considerably as a result of site and case-specific factors. Therefore, to select actions that provide the maximum benefit whilst minimising the cost (financial and temporal), suitable guidance is often required. One way businesses obtain this is to use one of the freely available carbon calculators; however, these vary considerably in their form and complexity. This paper considers the relevance of these variations for practical decision making, and concludes that some of the more simple to use tools may result in inaccurate estimates, and provide insufficient detail. Therefore, despite their additional complexity, more detailed systems are likely to be of greater use, and remain well within the capacity of on-farm use.

Keywords: carbon accounting tools, greenhouse gas mitigation

INTRODUCTION: The contribution of agriculture to greenhouse gas (GHG) emissions is well-documented, with the FAO (2006) estimating that worldwide, animal (mainly ruminant) agriculture alone is responsible for 18% of anthropogenic GHG emissions (particularly CH_4). This is higher than many estimates for agriculture, as a whole, (generally around 10% - e.g. Harvey & Pilgrim, 2011) due to the LCA approach taken (O'Mara, 2011). Nevertheless, it is clear that the livestock industry plays a significant role in climate change, and as a result will continue to be under pressure to improve its performance. There are a number of options for mitigating such emissions, including changing feeding practices, using dietary additives, and improving the management of manure and slurry (Smith et al., 2008); however, if suitable mitigation options are implemented, then producers require appropriate guidance. One element is the provision of carbon calculators for use on the farm (e.g. Hiller et al., 2011), but these vary considerably in complexity, data demands, and reporting detail. This study evaluated a range of free (and therefore easily accessible) carbon calculators, and determined their suitability for guiding livestock producers in the selection of practices which mitigate on-farm GHG emissions.

1. MATERIAL AND METHODS: This study comprised two parts. Firstly, the selection and characterisation of carbon calculators purporting to be suitable for use on European livestock farms. Secondly, the evaluation of those tools to determine their suitability for guiding practical decisions relating to the amendment (or adoption of new) practices, and to mitigate GHG emissions using a series of case-study examples.

1.1. Tool selection & characterisation: A review of freely available carbon calculators intended for use in European livestock agriculture was performed to identify a series for in-depth evaluation. Each tool was characterised against a number of criteria considered important for determining suitability for use by farmers in reducing GHG emissions, including, for example, information on the tools' objective, the general approach adopted, data input requirements, user friendliness and ongoing maintenance.

1.2. Scenario-based evaluation: A number of case-study farms were identified from across Europe (France, Italy, Poland, the UK) and data on their operation, productivity and input quantities (e.g. nutrients, pesticides, fuel/energy, water, etc.) were collated during 2009/10. All farms reported growing arable crops, but this was mainly for livestock feed; therefore, they are considered typical of many livestock-orientated businesses. Data from each farm was run through each tool, and the estimated GHG emissions (tCO_2e ha-1) from each evaluated to identify/explain differences in the results, particularly with respect to any implications for guiding mitigation strategies. The scenarios were on a 'production only basis', and did not consider non-productive areas (e.g. margins, hedgerows, etc.), since approaches for including these are different (limiting comparability) and produce variable/uncertain results (Smith et al., 2007).

2. RESULTS AND DISCUSSION

2.1. Tool selection & characterisation: Five suitable tools were identified and selected for use in this study: CALM (www.calm.cla.org.uk), CCalC (www.ccalc.org.uk),
COOL (www.unilever.com/aboutus/supplier/sustainablesourcing/tools), CPLANv0 (http://www2 .cplan.org.uk) and IMPACCT (http://sitem.herts.ac.uk/aeru/impacct). Other tools were considered for inclusion but were rejected either because they are unsuitable for mainstream agriculture or require a fee (limiting the scope for and ease of uptake).

Like many other forms of decision support tool, carbon calculators tend to be developed for a specific purpose and/or end user. For example, three (CALM, CPLAN & CCalC) are designed for UK users, whilst IMPACCT is intended for an EU and COOL a global audience (which in the latter case means that data requirements may not be in a format familiar to European users). Equally, whilst all the tools aim to calculate an overall carbon balance, for CALM and CPLAN this is the main objective, whilst IMPACCT and COOL were designed to identify or compare specific mitigation options and the carbon balance is a consequence of this process. In addition, some (e.g. CPLAN) are also intended to inform policy. CCalC has a supply chain focus with optimisation of the chain as a whole, rather than just the farm, as the main objective. Such differences can influence the form taken by a tool, as well as its level of complexity, functionality and the user support provided. For example, two (CALM, CPLAN) are web-based systems and therefore limit the amount of input data they require, and while this ensures that they are the easiest to use, it also means that they produce outputs of limited depth. Others are downloadable, either in the form of spreadsheets (COOL, CCalC) or bespoke software systems (IMPACCT), and these generally make higher input data demands, but as a result produce outputs with greater detail. Both IMPACCT and COOL for example, also consider costs and offer information on other environmental impacts that may occur.

Examples of these differences can be seen in the livestock-specific data requirements. Most tools require entering livestock numbers (although CCalC requires live weight instead - no doubt reflecting its supply chain focus), but some (CALM, CPLAN, COOL) divide livestock numbers by type, productivity and/or age. Only two tools include the effect that the amount of time housed and different feed types have on GHG emissions, with both IMPACCT and COOL requiring data on the percentage of time and the amount broken down by type/dry matter content, respectively. When crops are grown on the farm, CPLAN does not consider the type of inorganic fertiliser or manure/slurry used, requiring only the amount of product or manure applied, and makes no allowance for variations in nitrogen content. Equally, there are differences in the way output data is broken down, with some tools (e.g. IMPACCT, CALM – to a greater or lesser extent) breaking down modelled GHG emissions by both component (e.g. manure deposition on pasture, enteric fermentation, storage, etc.) and by gas (CO_2, CH_4, N_2O), as well as giving the CO_2 equivalent of each component and in total. Others (CPLAN, COOL) in contrast, make little attempt to do this, preferring instead to offer only a basic breakdown (e.g. livestock, crops, energy/fuel, etc.). Therefore, it is inevitable that these differences will affect result accuracy (see section 2.2).

2.2. Scenario-based evaluation: Comparisons between farms are fraught with difficulty due to complex site-specific differences and variations in data recording; however, it is evident (Figure 1) that considerable variation exists in the level of agreement between tools for individual case-studies. This is most noticeable for emissions as a direct result of livestock management, with CPLAN, in particular, resulting in considerably higher estimates of emissions than any other tool, in some cases. The version of CPLAN assessed here is one available for free (to ensure access comparability with other tools), and is a much-simplified version of a subscription service offered by the same provider. As such, it has simple data entry requirements, and makes a number of assumptions in its model, often seeming to assume a worst case scenario. This (as the site itself recognises) means that the results should only be considered a guideline. There is also considerable variation in the estimates that result from the application of nutrients (including organic manures/slurries after they leave the store) to cropland and grassland. Again, this can be related to the degree case-specific factors can be included, with some models making little or no allowance for variations in the nitrogen content of applied materials, whilst others allow this as a consideration (section 2.1).

It would appear that despite often being the easiest to use, those tools with the least scope for considering actual farm practices and site-specific specific circumstances, make the most assumptions and have the most potential for overestimation (tending to adopt the precautionary principle). In contrast, COOL, which is probably the most detailed of the tools in terms of the extent situation-specific data can be entered, tends to produce lower GHG emission estimates than any of the other tools assessed (although generally within a similar range as most), and although this may, to some degree, be subject to differences in the emission factors used (due to its global nature), there is little doubt that increased sensitivity to case-specific factors should increase the accuracy of results, something particularly important when tools are used to steer on-farm GHG emission mitigation strategies.

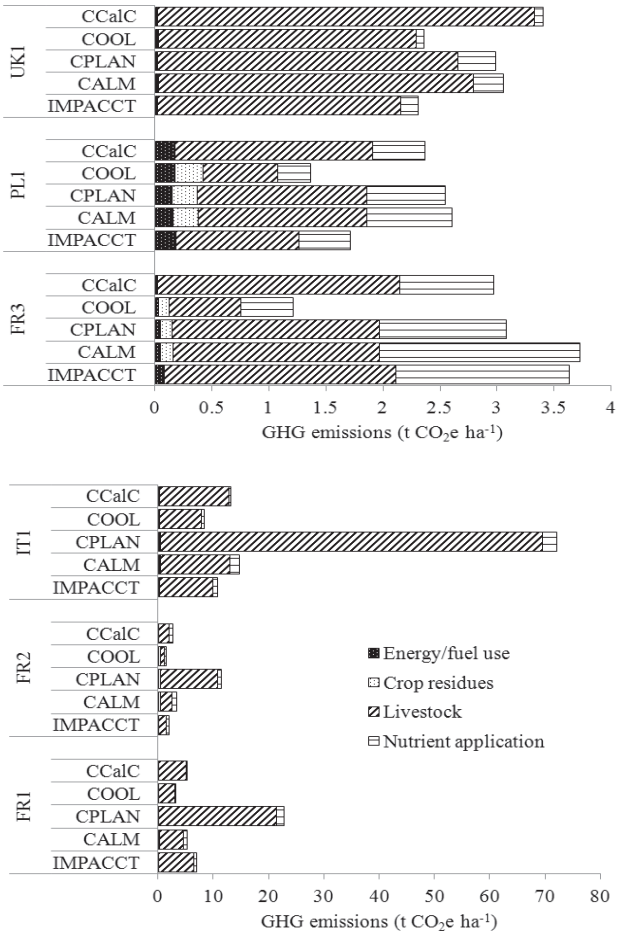

Figure 1. Categorised greenhouse gas emission estimates for six case-study livestock farms using five free agricultural carbon calculators.

CONCLUSION: The above discussion suggests that all the assessed tools have their strong points, but that their suitability for guiding on-farm decisions may vary. The more simple tools (most notably the free version of CPLAN) are quick and relatively straightforward to use, allowing non-specialist users to obtain initial understanding of the GHG emissions related to their businesses, without too much effort. However, their ease of use also works against them, in that they inevitably need to make a number of assumptions that more complex systems can obtain real data, and although in some cases this may not lead to too great an error, in some it will mean that overestimates may occur, since mitigation actions and/or other case-specific factors cannot be included. In addition, more complex tools are capable of providing a detailed breakdown of emissions, allowing the identification of specific areas of concern, and in some cases (e.g. IMPACCT) providing guidance on mitigation options. Therefore, although they are more complex and time-consuming to use, they are likely to be of greater benefit within the context of formulating GHG emission reduction strategies for farm businesses.

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HIGH RISE LAYER HOUSE AMMONIA EMISSIONS MEASURED BY THE NAEMS

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ABSTRACT: Air emissions from six high-rise layer houses were monitored for two years as part of the National Air Emissions Monitoring Study (NAEMS) and included ammonia (NH_3), hydrogen sulfide, carbon dioxide, volatile organic compounds, and particulate matter. The monitoring sites were located in North Carolina, Indiana and California with two identical houses at each site. The measurements were conducted simultaneously and with the same methods at each site. This paper presents an empirical NH_3 emission model for high-rise houses based on two years of daily means of NH_3 emissions from six layer houses. The average daily mean NH_3 concentrations ranged from 15.2 to 51.9 ppm in the exhaust air and from 0.91 to 1.90 ppm in the house inlet air. The average daily mean hen-specific NH_3 emission was 0.87 g/d-hen. The average daily mean hen-specific emission rate ranged from 0.59 g/d-hen in North Carolina to 1.08 g/d-hen in Indiana. There was excellent agreement between the two replicated houses at each of the three farms. Individual house emissions were 0.95 and 0.94 g/d-hen in California, 1.03 and 1.13 g/d-hen in Indiana, and 0.59 and 0.59 g/d-hen in North Carolina. The effects of influencing factors, such as exhaust temperature and hen live mass density on NH_3 emissions will be presented along with a daily mean NH_3 prediction equation.

Keywords: air quality, ammonia, emission model, prediction equation

INTRODUCTION: The National Air Emissions Monitoring Study (NAEMS) included continuous measurements of ammonia (NH_3), hydrogen sulfide, particulate matter and volatile organic compounds emissions from high-rise layer houses at each of three selected layer farms for a period of two (2) years starting in 2007. The farms were located in California (CA2B), Indiana (IN2H), and North Carolina (NC2B). An on-farm instrumentation shelter at each farm housed instruments for continuously measuring pollutant concentrations, house ventilation rates, and environmental variables. All houses were mechanically-ventilated and direct monitoring of fan operation plus on-site fan testing provided reliable airflow rate data. Ammonia concentrations were measured with a multigas photoacoustic infrared gas analyzer (Innova Model 1412, LumaSense Technologies A/S, Ballerup, Denmark). The objective of this paper was to develop an empirical model for NH_3 emissions from high-rise layer houses based on the NAEMS data.

Reported measurements of NH_3 emissions from high-rise layer houses were reviewed and compared with data collected from the NAEMS (Table 1). Only studies with more than 10 d of testing were selected. Airflow (Q) was estimated by fan monitoring (FM) or CO_2 balance (CB). Ammonia concentration (C) was measured with a Drager sensor (DS), a chemiluminescence analyzer (CL), or a photoacoustic infrared analyzer (PI).

Table 1. Ammonia emissions from high-rise layer houses reported from selected studies.

Loc	Q	C	Area	# days	Mean (±SD) Emission Rates				References
			m^2		kg/d	g/d-m^2	g/d-AU	g/d-hen	
IN	FM	CL	6694	125	387	57.8	509	1.57±0.56	Lim et al., ‘04
IN	FM	CL	5304	263	343	69.3	468	1.47±0.77	Heber et al., ‘05
IN	FM	PI	6039	518	249	43.8	386	1.13±0.43	Ni et al., ‘12
IA	FM	DS	2784	360	-	-	364	1.12	Yang et al., ‘00
IN	FM	CL	5304	261	258	51.9	342	1.10±0.42	Heber et al., ‘05
IN	FM	PI	6039	518	223	37.9	335	1.03±0.40	Ni et al., ‘12
OH	FM	CL	4221	95	213	50.5	326	1.31±0.48	Lim et al., ‘08
OH	FM	CL	4221	93	156	36.8	313	0.93±0.31	Lim et al., ‘08
IA	CB	DS	1878	75	132	70.1	308	0.95±0.29	Liang et al., ‘05
CA	FM	PI	1075	603	32	30.4	293	0.94±0.86	Lin et al., ‘11
PA	CB	DS	2588	25	83	32	286	0.88±0.36	Liang et al., ‘05
CA	FM	PI	1075	583	33	32.7	282	0.95±.49	Lin et al., ‘11
IA	CB	DS	1878	84	116	62	273	0.84±0.26	Liang et al., ‘05
IA	CB	DS	1878	84	60	31.9	263	0.81±0.25	Liang et al., ‘05
IA	CB	DS	1878	75	66	35	260	0.80±0.26	Liang et al., ‘05
PA	CB	DS	2588	25	73	28.3	253	0.78±0.34	Liang et al., ‘05
NC	FM	PI	3186	613	54	17.2	201	0.59±0.18	Wang-Li et al., ‘12
NC	FM	PI	3186	613	55	18	195	0.59±0.21	Wang-Li et al., ‘12
IT	FM	PI	1302	42	26	20	144	0.44	Fabbri et al., ‘07

RESULTS AND DISCUSSION: A single correlation was used to evaluate the effects of exhaust temperature (T) and live mass density (D) on area-specific emissions from full and active houses. The live mass density equaled total flock mass divided by layer room area. Full and active layer houses represented that molting and flock replacement periods were not included in the emission model. Exhaust temperature (T) is considered an independent variable, representing thermal variables, such as ambient and house temperature and relative humidity, house static pressure, solar radiation, wind speed, and ventilation rate. Live mass density was also considered as an additional independent variable since it is independent of exhaust temperature. Live mass density effectively represents the flock characteristics, e.g.,

number of hens, hen mass, number of tiers, hens per cage, egg production, manure production, and feed consumption. The NH_3 emission was positively influenced by D and negatively influenced by T (Figure 2).

It appeared that D coupled with T had the greatest influence on NH_3 emission in full and active layer houses. Choosing T and D to represent environmental and flock factors, the empirical NH_3 emission prediction equation [1] was developed from the daily means from six layer houses.

$$E = -24.35 - 1.34T + 1.71D, \qquad R^2 = 0.35 \tag{1}$$

Where E = emission, g/d-m^2, D = live mass density, kg/m^2, and T = exhaust temperature, °C.

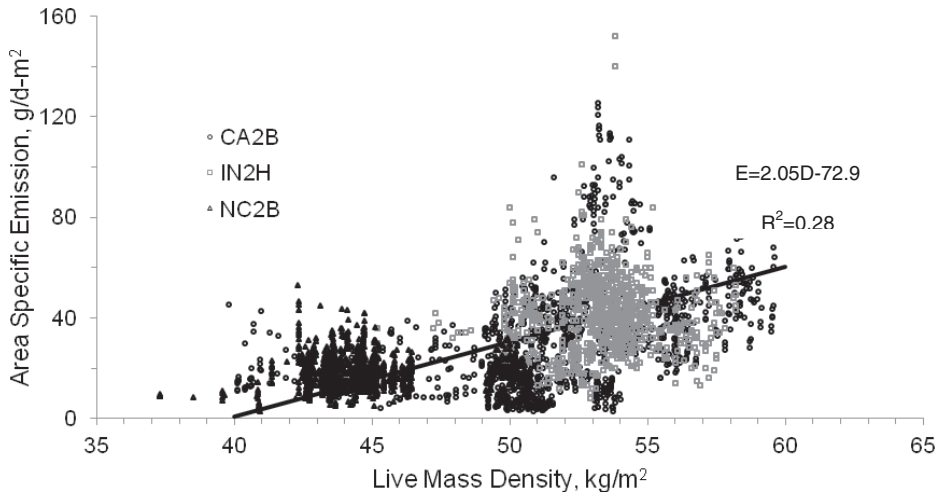

Figure 1. Influence of live mass density on daily mean area-specific NH_3 emission. Note: n=1065, 912, and 1310 for CA2B, IN2H, and NC2B, respectively. p<0.001.

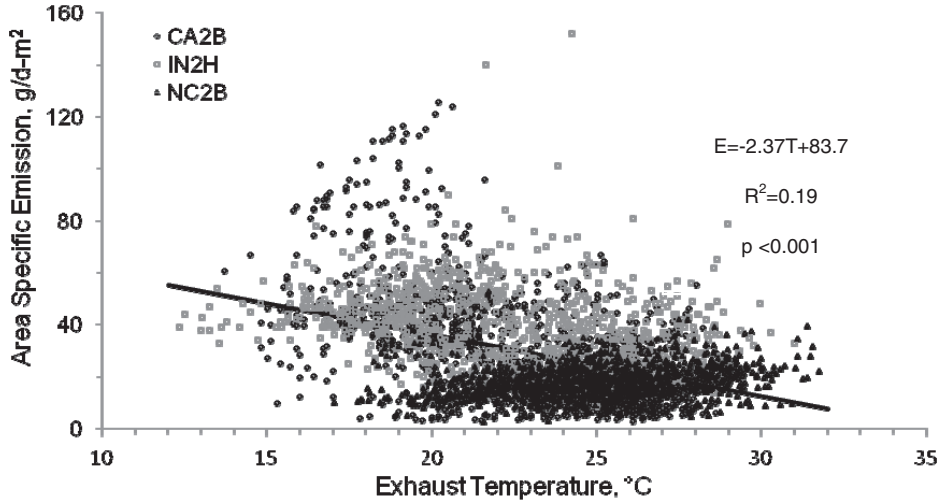

Figure 2. Influence of exhaust temperature on daily mean area-specific NH_3 emission. Note: n=1065, 912, and 1310 for CA2B, IN2H, and NC2B, respectively. p<0.001.

The differences between measured and predicted NH_3 emission rates using equation 1 at CA2B, IN2H and NC2B were compared (Table 2). The differences were 6.1%, 11.1% and 4.0% for CA2B, IN2H, and NC2B, respectively. Therefore, the estimation model provided reasonable estimates of NH_3 emissions.

Table 2. Differences between predicted and measured NH_3 emissions.

Parameter	CA2B	IN2H	NC2B
Average live mass density, kg/m^2	49.2	53.3	44.8
Average exhaust temperature, °C	22.4	22.4	24.7
Average predicted emission rate, g/d-m^2	29.7	36.8	19.1
Average measured emission rate, g/d-m^2	31.5	40.9	18.3
Difference, %	-6.1	-11.1	4.0

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FEEDING STRATEGIES TO MINIMIZE ENVIRONMENTAL IMPACT OF GROWING PIGS

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ABSTRACT: In pig production systems, feed composition plays an important role in the production of Green House Gas (GHG) through methane and nitrous oxide emissions. The excretion of volatile solids (VS) is the principal source of methane emissions from pigs, through manure handling systems. The nitrous oxide concentration emitted is a function of excreted nitrogen (Nex) within the manure. In this paper, a computer-based growth simulation study was undertaken to show ways economic profitability is affected when the environmental impact associated with Nex and Vs excretions is minimized. The computer program used links a linear program for least-cost diet formulation, a stochastic pig growth model, and a genetic algorithm to find the best solution for an objective function (OF). Different OF combining VS, Nex and gross margin (GM) were investigated for Normal or Lean pig genotypes with liquid (anaerobic lagoons) or solid waste (deep litter) effluent disposal systems. Overall, lean genotypes produce a higher gross margin, less nitrogen and less volatile solid than normal genotypes. For both genotypes, Nex can be reduced by up to 15% to 20% without reducing profitability. However, this reduction in Nex is associated with an increase in VS within the manure, thus no real reduction in the total CO_2-equivalent produced is observed in an anaerobic lagoon or deep-litter effluent treatment system. Computer simulation of growth is a useful tool that can be used to find specific feeding strategies which reduce GHG emissions and maximize profitability in growing pig herds and thus for different manure treatment systems.

Keywords: pigs, volatile solids and nitrogen excretion rates, pig growth model

INTRODUCTION: The NZ pork industry is regarded as a 'minor' category for Green House Gas (GHG) emissions, releasing an estimated 180,000 tonnes of CO_2-equivalents (CO_2-e) against the total agricultural budget of around 34 million tonnes. The information gathered, to date, on the industry identified the manipulation of feed (through composition) as a potential GHG mitigation strategy for the industry. Feed composition plays an important role in the production of methane and nitrous oxide emissions from agriculture. Currently, diets are formulated to meet the animal's nutritional requirements for growth and the on the availability of feed ingredients (cost and supply), and to do this as economically as possible. Computer pig growth simulation models are now used commercially to evaluate the profitability of different feeding strategies (de Lange et al., 2001). However, for a given farm, the number of diets fed, their energy content (d), amino acid content (using lysine as a proxy,) (r), the quantity fed (p) and the length of time a diet is fed (t) can vary, thus giving a large number of possible feeding strategies (F, as many as 1050). A feeding strategy F is a finite set of diets: F = (d1, r1, p1, t1; d2, r2, p2, t2; …; dn, rn, pn, tn), where each diet consists of a quadruple (d, r, p, t). Adding nonlinear optimisation methods to a growth model allows an F to be found that yield a maximum for an objective function (OF). A computer simulation program was developed which links a linear program for least-cost diet formulation, a stochastic pig growth model and a genetic algorithm (GA) to find the maximum for the OF (Morel et al, 2010). At present, when pigs' diets are formulated, no consideration is given to reducing GHG emissions. The

excretion of volatile solids (VS) is the principal source of methane emissions from pigs through manure handling systems. The concentration of excreted nitrogen (Nx) within an animal's manure will depend upon the extent the dietary protein intake matches the animal potential for growth. Tailoring diets to each pig genotype to reduce both Nx and VS is a feasible solution to reduce the GHG in the pig industry. In this paper, a computer-based growth simulation study was undertaken to show ways economic profitability is affected when the environmental impact associated with nitrogen and volatile solid excretions is minimized. This was investigated for two pig genotypes and two types of effluent disposal systems: anaerobic pounds and solid waste.

1. MATERIAL AND METHODS: Beside growth and financial performances, the computer program (Bacon Max) described by Morel et al. (2010) was updated to simulate both nitrogen (Nex) and volatile solid (VS) excretion. Nitrogen excretion is simulated, as previously described (Morel and Wood, 2005), and the volatile solid excretion rate per kg feed for each ingredient is calculated with the IPCC (2006) equation.

Both Nex and VS are then incorporated with the gross margin (GM) in an Objective Function (*OF*):

OF = *a* x GM + *b* x Nex + c x VS

Varying the weighing factors (a,b,c) allows placing more or less emphasis on profitability and/or environmental impact when searching for a best feeding strategy. The factor b and c can also represent the CO_2e cost ($) associated with both Nex and VS excretions. In New Zealand, a cost of $25 per ton (2.5c per kg) CO_2e has been proposed. The quantity of Nex (kg) and VS (kg) excreted are converted into kg CO_2e using the equations given in NZGGI (2011). Based on these equations, for an anaerobic lagoon effluent treatment 1 kg Nex is equal to 6.21 kg CO_2e and 1 kg VS to 5.96 kg CO_2e, and for a deep-litter system with solid storage 1 kg Nex is equal to 15.47 kg CO_2e and 1 kg VS to 0.095 kg CO_2e. In the case of a covered-lagoon burning methane gas system, 1kg VS is equivalent to 0.271 kg CO_2e. The computer simulations were performed using the feed cost and price schedules current in New Zealand in April 2011. Growth between 20 kg and 92 kg live weight was simulated for two pig genotypes varying in their minimal lipid to protein ratio (minLP) and maximum protein deposition potential (PDmax): normal (0.75; 160 g/d) and lean (0.6; 200 g/d). The a value for GM in the objective function was always set to 1, the b values for Nex and the c values for VS varied between 0 and 100. Each genotype x OF combination was run 10 times. The GA had a population size of 20 feeding strategies and the search was stopped when the OF did not improve for 10 iterations.

2. RESULTS AND DISCUSSION: For the gross margin per pig, volatile solid excretion and nitrogen excretion and CO_2e of a normal and lean pig genotype, when the feeding strategies are optimised to reduce either nitrogen excretion or volatile solid excretion, are presented in Table 1. Overall, lean genotypes produce a higher gross margin, less nitrogen and less volatile solids than a normal genotype.

Table 1: Objective function weighing factor, gross margin (GM), nitrogen excretion (Nex), volatile solid production (VS), and CO_2 equivalent in deep litter and anaerobic lagoon for Normal and Lean pigs genotype.

Factor					CO_2 equivalent (kg)			
Genotype	b (Nex)	c (VS)	GM ($)	Nex (kg)	VS (kg)	Deep Litter	Lagoon	Lagoon - Methane
Normal	0	0	48.77	2.51	30.3	41.8	188.0	23.8
Normal	0	0.47	46.88	2.74	25.6	44.7	162.8	23.9
Normal	0	1	44.31	2.72	22.1	44.1	142.5	22.9
Normal	0	10	27.02	2.24	14.5	35.9	96.5	17.8
Normal	0	100	5.88	2.22	14.9	35.8	98.9	17.9
Lean	0	0	62.74	1.95	30.1	33.0	183.3	20.2
Lean	0	0.47	60.32	2.20	25.4	36.5	158.6	20.6
Lean	0	1	56.02	2.22	19.0	36.2	121.8	18.9
Lean	0	10	42.73	1.74	13.1	28.1	85.5	14.3
Lean	0	100	27.57	1.97	14.1	31.8	92.4	16.0
Normal	0	0	48.77	2.51	30.3	41.8	188.0	23.8
Normal	0.387	0	48.97	2.40	31.1	40.1	192.1	23.3
Normal	1	0	48.25	2.48	30.6	41.3	190.0	23.7
Normal	10	0	46.98	1.98	32.5	33.6	197.2	21.1
Normal	100	0	25.82	1.54	32.8	26.9	196.6	18.4
Lean	0	0	62.74	1.95	30.1	33.0	183.3	20.2
Lean	0.387	0	62.56	1.93	30.0	32.6	183.0	20.1
Lean	1	0	62.66	1.87	30.5	31.8	185.3	19.9
Lean	10	0	61.98	1.69	30.7	29.0	185.4	18.8
Lean	100	0	52.12	1.42	30.7	24.9	183.6	17.1

For both genotypes, nitrogen excretion can be reduced by up to 15% to 20% with only a small reduction in profitability. In this study, as in Morel and Wood (2005), the reduction in nitrogen excretion is obtained through a reduction in the total crude protein intake through the use of synthetic amino acid, which allows providing the right amount of ideal ileal digestible protein to match the pig's protein deposition potential. De Lange et al. (1999) and Henman and Smits (2001) demonstrated that formulating a diet based on digestible ideal ileal balanced amino acid and using synthetic amino acid is the best way to maximize profitability and maximize nitrogen utilization. However, this reduction in Nex is associated with an increase in VS, thus no real gain is achieved in terms of reducing CO_2e. Given that VS is mainly a function of ingredient digestibility, the scope for a reduction without a negative impact on profitability is limited, as highly digestible feedstuff are expensive. From a dietary perspective, further major reductions in Nex and VS can be achieved by increasing feedstuff protein and energy digestibility through low-cost feed processing techniques or the use of in-feed enzymes. Deep litter systems produce 4 to 5 time less CO_2e than a conventional anaerobic lagoon; however, covering an anaerobic lagoon and harvesting the methane to burn it results in the lowest level of CO_2e. Such systems are now implemented in New Zealand and worldwide. Overall, the best strategy is to

minimize nitrogen excretion and to use a covered anaerobic lagoon effluent system and burn the methane produced.

CONCLUSION: It is concluded that growth computer simulation is a useful tool in finding specific feeding strategies which reduce GHG emissions and maximize profitability in growing pig herds and thus for different manure treatment systems.

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MATHEMATICAL MODELING OF WEIGHT AND THERMAL BALANCES DURING WINDROW COMPOSTING OF LIVESTOCK EFFLUENTS

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ABSTRACT: A mathematical model of weight and thermal balance was developed to understand the impact of windrow physical characteristics on the kinetics of O2 consumption, temperature, water vapor and carbon dioxide emissions**.**

Keywords: windrow composting of livestock effluents, modeling, gaseous emissions, kinetic rates, porosity

INTRODUCTION: On-farm composting of livestock effluents is a complex bioprocess, requiring many experiments to optimize the process. A modelling approach enables reducing the time spent enhancing composting efficiency by increasing transformation rates and reducing polluting gaseous emissions. A dynamic mathematical model of the biodegradation of organic matter (OM) during the composting process was previously developed (Oudart et al., 2011). This model represents the effect of the biodegradability of OM on the kinetics of oxygen (O_2) consumption and carbon dioxide (CO_2) emissions. Transformation rates are influenced by internal temperature and water content (W_C) (Abd El Kader et al., 2007). Representing water vapour emissions (H_2O_g), the kinetic of internal temperature and the final compost agronomical quality during windrow composting required including more processes, such as heat and O_2 transfers. In the literature, most models representing heat balances are designed to describe composting in a laboratory reactor with controlled aeration conditions (Sole-Mauri, 2007; Vlyssides, 2009). The innovation of our model is the representation of full-scale composting with passive aeration by a self-heating process. The objective of this paper is to present the general features of this model of heat and mass balances, which are influenced by physical factors such as humidity and porosity.

1. MATERIAL AND METHODS:

1.1. Model structure: Windrow is considered a homogeneous system composed of solid, liquid and gas phases with a homogeneous temperature. The gas phase is considered a perfect gas. The heat balance is calculated through modeling OM oxidation (Oudart et al., 2011) by using the flow of O_2 consumption, and then through biological heat production (H_{bio}). This heat is then split into latent (H_{lat}) and sensible (H_{sens}) heats. H_{lat} is used to calculate H_2O_g emission flux. H_{sens} is used to calculate heat storage and then temperature of the heap (T) kinetic, and convective and conductive losses. Convective losses and O_2 input are estimated by calculating the mass flow rate of the dry air (Qm_{dryair}). This flow is estimated by the "chimney effect"; therefore, by the difference between ambient temperature (T_a) and T and is influenced by porosity (□), water content and heterogeneity (pO_{2eff}) of the heap. This calculation method enabled the representation of the system's self-ventilation, as observed during on-farm composting.

1.2. Model equations: Heat balance is calculated following equation (1):

$$\frac{d\left(WW(t)\cdot Cp(t)\cdot T(t)\right)}{dt} = Qm_{dryair}(t)\cdot\left(H_I - H_O\right) + UA\left(T - T_a\right) + \frac{d\left(H_{sens}\right)}{dt} \quad (1)$$

where WW is the wet weight of the heap (kgWW), Cp the specific heat of compost mixture (J/kgWW/K), H_I and H_O the enthalpies of inlet and outlet air (J/kg of dry air), U the overall heat transfer coefficient (W/K/m²) including conductive and radiation losses, A the exchange surface between windrow and atmosphere (m²). The produced H_{bio} (in J) is linked to O_2 consumption by heat of O_2combustion (H_c in J/kg consumed O_2). H_{bio} is then divised into H_{sens} and H_{lat} by a latent heat dividing variable (H_{DivLat} in J/J):

$$\frac{dH_{lat}}{dt} = \frac{dO_{2cons}}{dt}\cdot H_c \cdot H_{DivLat} \quad ; \quad \frac{dH_{sens}}{dt} = \frac{dO_{2cons}}{dt}\cdot H_c \cdot \left(1 - H_{DivLat}\right) \quad (2)$$

H_{DivLat} depends on W_C and five others parameters: W_{Cmin}, W_{Cmax}, $H_{DivLatMin}$, $H_{DivLatMax}$ and pH_2O_{bd}. W_{Cmin} and W_{Cmax} are, respectively, minimal and maximal W_C necessary to obtain the minimal and maximal H_{lat} dividing parameters ($H_{DivLatMin}$ and $H_{DivLatMax}$). $H_{DivLatmax}$ depends on the capacity of the substrate to bound water, and then to reduce water evaporation, expressed by the parameter of bound water (pH_2O_{bd}).

$$H_{DivLat} = \text{if}\begin{cases} W_C < W_{Cmin} ; & H_{DivLatMin} \\ W_C < W_{Cmax} ; & H_{DivLatMin} + \dfrac{H_{DivLatMax}\cdot pH_2O_{bd} - H_{DivLatMin}}{W_{Cmax} - W_{Cmin}}\cdot\left(W_C - W_{Cmin}\right) \\ W_C > W_{Cmax} ; & H_{DivLatMax}\cdot pH_2O_{bd} \end{cases} \quad (3)$$

Cp is calculated using the relation of Haug (1993), depending on OM content and W_C. Qm_{dryair} is calculated by the chimney effect:

$$Qm_{dryair} = K\cdot\sqrt{\frac{\left|T_V - T_{Va}\right|}{Tv}} \quad (4)$$

$$\frac{K}{K_{max}} = \text{si}\begin{cases} \theta < \theta_{LL} ; & K_{min} \\ \theta < \theta_{HL} ; & \dfrac{1 - K_{min}/K_{max}}{\theta_{HL} - \theta_{LL}}\cdot\left(\theta - \theta_{LL}\right) + K_{min}/K_{max} \\ \theta > \theta_{HL} ; & 1 \end{cases} \quad (5)$$

where K is a regulation variable of the dry air mass flow (kg of dry air h^{-1}), T_V and T_{Va} are, respectively, the windrow and the ambient virtual temperatures (K). K depends on the porosity of the heap and two parameters (θ_{LL} and θ_{HL}), representing, respectively, the low and high limits of porosity in obtaining the minimal and the maximal value of K (eq. 5).

Wet weight balance results from dry matter and H_2O balances. Loss of dry matter results from loss of carbon by CO_2 emissions and from metabolic water production by microbial growth. Water balance also results from this process and from H_2O evaporation calculated by the latent vaporization heat. O_2 balance results from input and output of dry air and consumption by microbial growth. Available O_2 for

microorganisms depends on its diffusion into the biofilm and is represented by a factor of efficacy of oxygen (pO_{2eff}), expressing the heterogeneity of the distribution of biofilm and porosity into the heap. This parameter represents the percent of the O_2 input that diffuses into the biofilm. Variation of the volume is calculated by a parameter p_{Coll}, representing the potential of the heap to collapse, to compact or to retain the same porosity with the loss of volume. Microbial growth is then limited by temperature, water content and oxygen concentration.

This model contains 30 parameters, including 5 parameters depending on the substrate nature (initial biomass content and metabolic water production yield), as presented in Oudart et al. (2011), and on the heap's physical characteristics (pO_{2eff}, pH_2O_{bd}, p_{Coll}). The model works on an hourly time step. It was programmed with the Vensim® software (Ventana System, USA).

1.3. Calibration data: To calibrate this model, experimentations presented by Paillat et al. (2005) and Abd El Kader et al. (2007) were used. All details are given in these papers. Results are presented for calibration of heap E, F, G and H for the first experiment and heap T_W for the second. The first four heaps are composed of different ratios of pig slurry, wheat straw, sawdust and sugar beet molasses, whereas the last one is composed of turkey manure. All five heaps had the same humidity (70%), but heap T_W had less porosity (45%) than the others (70%). Nine parameter values were taken from the literature, 2 parameters were calculated from experimental data, and others were calibrated using the Vensim ® optimizing tool.

2. RESULTS AND DISCUSSION Some results of parameter calibration are presented in Table 1 as determination coefficients for instantaneous and cumulative water emissions.

Table 1. Parameter values (pO_{2eff} and pH_2O_{bd}) and determination coefficient between experimental and simulated data for H_2O cumulative (R^2_{cumul}) and instantaneous (R^2_{inst}) emissions.

Parameter	Heap E	Heap F	Heap G	Heap H	Heap T_W
pO_{2eff}	0.072	0.053	0.051	0.058	0.020
pH_2O_{bd}	0.95	0.70	1	0.79	0.38
R^2_{cumul}	0.990	0.987	0.976	0.990	0.998
R^2_{inst}	0.946	0.896	0.880	0.902	0.855

The nature of the raw material had a significant interaction on water evaporation (pH_2O_{bd}). The heaps containing only wheat straw (E and G) retained less water than the heap with sawdust (F and H). For heap E, 95% of the initial water evaporated, whereas only 70% of initial water evaporated for heap F. This can be explained by the nature of the raw material: sawdust had more microporosity than wheat straw. To retain more water in the heap and to enhance transformation rates, and then to decrease composting time, requires use of raw materials with a water-holding capacity.

Oxygen was brought into the heap by self-heating of the matter. For heap E, F, G and H, between 5 and 7% (pO_{2eff}) of the oxygen brought by self-ventilation was necessary for microbial growth in perfect aeration conditions. For a more compacted heap (T_W), there was less oxygen diffusion into the biofilm. A decrease in the distribution of porosity and humidity will decrease the oxygen transfer into the biofilm. Flow of heat production is then lower, which reduces self-aeration and transformation rates.

During composting, latent heat decreased 80 to 40% of the biologically produced heat in conditions of high porosity (heap E to H). Between 80 and 90% of the sensible heat was lost by convection. In conditions of lower porosity, the ratio of latent heat was less (35% of total heat for heap T_W). Between 96 and 98% of the sensible heat was lost by convection, and the matter's temperature was lower than in good aeration conditions. To ensure better self-heating, transformation rates, and destruction of pathogens requires the insertion of a raw material to create macroporosity.

CONCLUSION: The developed model permits us to understand the impact of porosity, humidity and their distribution in the heap, on the inlet oxygen flow and diffusion, and on the self-heating capacity. Enhancing transformation rates and composting efficiency requires using a raw material with water-holding capacity, and mixing the initial matter to reduce heterogeneity of the distribution of humidity and porosity.

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PROTON ACTIVITY – THE MISSING LINK IN PREDICTING AMMONIA AND ODOR EMISSIONS FROM MANURE

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ABSTRACT: Emission of ammonia and obnoxious odors are a hazard to the environment and to health. Emission of NH_3 is a loss of mineral fertilizer at a cost to the farmer. The emission of the electroneutral gas-species is significantly influenced with acid-base reactions. Release of the most important volatile acid and base, therefore, affects NH_3 emissions. This study shows that gas emissions are influenced by transport of these solutes into surface layers of stored liquid, where acidity is affected by change in concentration of acid and bases. NH_3 emission from stored slurry illustrates this effect.

Keywords: ammonia, NH_3, CO_2, Slurry, modeling, pH prediction, diffusion transport

INTRODUCTION: Only uncharged gas species is released from slurry, i.e. the electroneutral solutes. Ammonia (NH_3) and hydrogen sulfide (H_2S) are a base and an acid, and therefore release and emission are influenced by the NH_3 to NH_4^+ and H_2S to HS^- relation, which is affected by the hydron $\{H^+\}$ activity. Hydron activity in slurry is buffered by total inorganic carbon ($TIC=(CO_2+HCO_3^-+CO_3^{2-})$, total ammoniacal nitrogen ($TAN=NH_3+NH_4^+$), organic acids and organic particles (Sommer and Husted 1995; Hafner et al. 2012), which must be included when assessing pH in the surface layers of NH_3 or H_2S sources, whether stored or applied slurry.

Most models used to predict NH_3 or odor emissions do not adequately acknowledge these volatile buffers, nor that pH in the surface layer is significantly affected by transport and release of these buffers. Additionally, NH_3 emission increases with increasing pH and the odorant H_2S increases with declining surface pH. This pH differs from pH in layers underneath (Cahn et al. 1998). Modeling $\{H^+\}$ is challenging because the activity is affected by a combination of chemical, physical and microbial processes. Moreover, the emission of NH_3 and odor components cannot be predicted by models that do not include surface pH.

The intention of this study is to develop a model that includes all reactions and processes that significantly affect gas emissions from slurry. The objective is use of the model to assess gas emissions that are in equilibrium with acid - base pairs and to develop simple operational models that account for pH at the source surface. We present model predictions of the oxonium ion $[H_3O^+]$ in a system with dissolved TIC and TAN. Further, we show the effect of diffusion on $[H_3O^+]$ in the surface layers of stored slurry.

1. MATERIAL AND METHODS: Release of gas from liquid into the atmosphere is often predicted with a two-film diffusion model (Kirk and Rachpal-Singh 1992). The model includes diffusion in a stagnant surface liquid layer and in a laminar air layer in the liquid surface, and the gas transfer between these two phases. The liquid phase below the stagnant liquid layer is stirred (homogeneous) and air above the stagnant air layer is also mixed (homogeneous).

The calculations assume that the barrier (resistances) to emission is diffusion through the stagnant liquid and air film layers, and the release from the liquid into the air. In the stagnant liquid layer, diffusion of the species CO_2, HCO_3, CO_3^{2-}, NH_3 and NH_4^+ is calculated (Table 1). Further, the chemical reactions in the surface layers (Table 1) affecting the gas release are included in the computations.

The considered slurry is composed of 0.1 M NH_4Cl and 0.2M $NaHCO_3$, therefore, change in pH can be estimated by use of the electroneutrality condition given in eq. 1 (Z_{system}=0) and the reactions presented in Table 1:

$$Z_{system} = ([NH_4^+] + [H_3O^+] + [Na^+] + [K^+] + [H^+]) - ([HCO_3^-] + 2\cdot[CO_3^{2-}] + [CH_3COO^-] + [Cl^-] + [OH^-]) \quad (1)$$

Table 1. Diffusion coefficients for the solutes and the gases (1; Kirk and Rachpal Singh 1992; 2: Ni 1999; 3: Zeebe 2011), equilibrium constants and Henry law constants of volatile components dissolved in slurry and manure (Beutier and Renon 1978) – temperature 25°C.

Diffusion coefficient			pK (-log(K) and K_H	
Component	$m^2\ s^{-1}$	Ref.	Reaction	Constant
CO_2(g) in air	$1.85\cdot10^{-3}$	1	$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$	4.75
NH_3(g) in air	$1.39\cdot10^{-3}$	1	$H_2O(l) - H^+(aq) + OH^-(aq)$	13.99
H_2CO_3(aq)	$0.80\cdot10^{-9}$	3	$CO_2(aq) + H_2O(l) \rightleftharpoons HCO_3^-(aq) + H_3O^+(aq)$	6.35
HCO_3^-(aq)	$1.10\cdot10^{-9}$	3	$HCO_3^-(aq) + H_2O(l) \rightleftharpoons CO_3^{2-}(aq) + H_3O^+(aq)$	10.33
CO_3^{2-}(aq)	$2.05\cdot10^{-9}$	3	$NH_3(g) \rightleftharpoons NH_3(aq)$	60.381
NH_3(aq)	$1.24\cdot10^{-9}$	2	$CO_2(g) \rightleftharpoons CO_2(aq)$	0.034
NH_4^+(aq)	$2.86\cdot10^{-9}$	2		

In the following sections, we present results derived from equations for the diffusion and reaction of the species in solution. It is assumed that chemical equilibrium is reached instantaneously. The slurry is initially stirred and therefore all species are homogeneously distributed at initiation, and determined by chemical equilibrium. Under these conditions, the problem is reduced to two coupled second order differential equations for [TAN] and [TIC]. When the diffusion coefficient for the species is different, the resulting equations are highly non-linear and complex. After solving these equations we can calculate concentrations for all species everywhere in space and time.

The intention of this presentation is to depict the effect of diffusion in the stagnant liquid layer; therefore, it is assumed that there is no air resistance to transport of the gas components CO_2(g) and NH_3(g). This assumption has the effect that [TAN] and [TIC] are zero at the liquid surface.

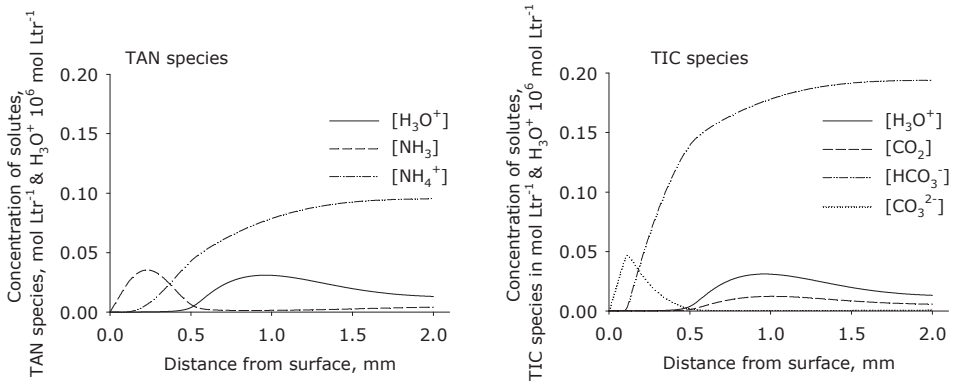

Figure 1. Left: Concentration of TAN species and Right: TIC species at increasing distance from the surface of a solution with of 0.1 M NH_4Cl and 0.2M $NaHCO_3$ – time from stirring 100 sec.

2. RESULTS AND DISCUSSION: The calculations show that after stirring where solutes are homogeneously distributed, then $[H_3O^+]$ concentrations at the surface are low due to emission of TIC (Fig. 1). As a consequence, the NH_3(aq) concentration in the surface is significantly higher than in the bulk of the solution. Due to the high concentration of NH_3(aq) in the surface layers, this component is downwards diffusion. This trait is counteracted by upward transport of NH_4^+ where concentration is low in the surface layers due to low H_3O^+. It is also observed that H_2CO_3 concentration in the surface is low due to high pH and CO_2 emission. Just below the surface at 1 mm depth, H_3O^+ concentrations increase. This is due to the diffusion coefficient NH_4^+ being higher than that of NH_3, and due to NH_3 emission, these processes contribute to H_3O^+ formation at about 1 mm depth, initially. Therefore, the concentration of the base NH_3 is low at 1 mm, whereas above this layer the low H_3O^+ causes NH_3 concentrations to be higher than at 1 mm depth (Fig. 2).

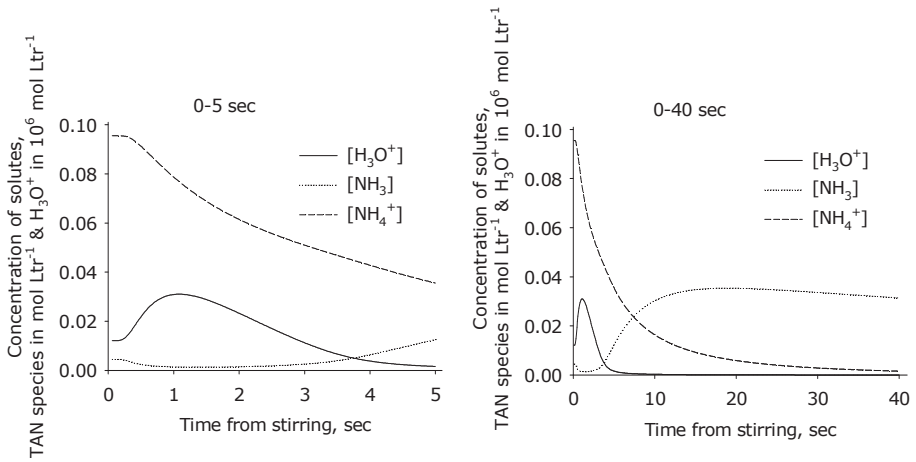

Figure 2. Concentration of NH_3, NH_4^+, CO_2, HCO_3^-, CO_3^{2-} and H_3O^+ at 0.1 mm depth with time from stirring, no resistance in the laminar air layer.

It is observed that the duration of $[H_3O^+]$ increase at 1 mm immediately after stirring is brief (Fig. 2). Thus, because $[H_3O^+]$ declines, NH_3 emission is initially high and causes TAN concentrations in the 0-2 mm layer to decline (Not shown).

In our calculations, diffusion of each species was calculated in contrast to most calculations, where one diffusion coefficient for the TAN and one for the TIC species is chosen. A sensitivity analysis was performed, keeping the average TAN diffusion coefficient unchanged by increasing the D_{NH3} and reducing D_{NH4} (Fig 3). This reduced $[H_3O^+]$ and $[NH_3(aq)]$ at the surface and NH_3 losses was reduced. The scenario shows how important it is to calculate diffusion of each species.

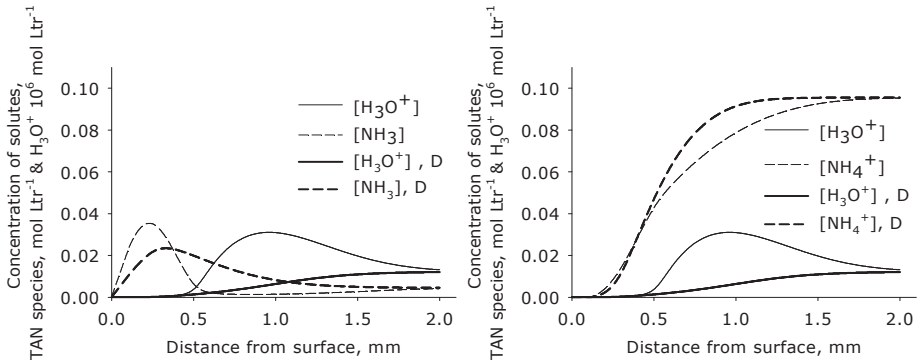

Figure 3. Concentration of NH_3 and H_3O after 100 sec the thin curves (Indicated with a D in the legends to symbols) are concentration calculated using diffusion coefficients in table 1. The thick curves are D_{NH3} at 2 10^{-9} m^2 s^{-1} and D_{NH4} 1 10^{-9} m^2 s^{-1}.

CONCLUSION: The aim was to develop a pH and NH_3 (Odor) emission model that encompasses all components and species in the calculation. The analysis performed with the diffusion modules of the model indicates the importance of correctly calculating surface H_3O+ concentrations. We will include micrometeorology in the model, and also the rate of important processes; it was identified that dehydration of H_2CO_3 is an important rate-limiting process (Kirk and Rachpal Singh 1992, Hafner et al. 2012). Further, solid phases chemistry, absorption into negatively-charged organic components and rate of microbial transformation of organic components will be included in the model.

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INTERMITTENT MEASUREMENTS TO ESTIMATE AMMONIA EMISSIONS FROM MANURE STORAGE SYSTEMS

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ABSTRACT: The production of animals must comply with several environmental requirements. Monitoring ammonia emissions from agricultural buildings and storage systems is one of them. To reduce cost, techniques were developed that use inexpensive measuring equipment and do not require long periods of measurements, a technique based on intermittent measurements of ammonia was developed for mechanically ventilated barns. More specifically, easily-measured variables, such as ventilation rate, temperature, and animal weight are measured continuously, while the ammonia emission rate is measured intermittently at six well-selected days per year. Mathematical modelling techniques are subsequently used to estimate the ammonia emission rate online. The intermittent ammonia measurements are used to regularly calibrate the model. However, for manure stores, this technique has never been applied due to lack of a reliable ventilation rate measurement system. The objective of this paper is to introduce a procedure to determine the ammonia emissions from manure storage systems in the field, based on intermittent measurements of the ammonia emission rate. In this study, an experimental tank was filled with fattening pig slurry. One was covered with a mechanically ventilated cover. Based on the knowledge that ammonia emissions are strongly related to air and manure temperature, a technique was developed to estimate ammonia emissions online. A steady-state regression model was used to calculate the cumulative ammonia emissions over the complete measurement period with 9% accuracy. This paper demonstrates the possibilities of model-based procedures for the development of an inexpensive system for determination of ammonia emissions.

INTRODUCTION: Intensive livestock production is of major importance to the economies of many countries, but is also connected with a number of environmental effects, including airborne emissions. In Europe for example, pig production is concentrated in several regions characterised by large-scale intensive farms. Ammonia emissions from liquid manure inside pig houses are related to the ammonia concentration difference between the manure and the air above the manure, manure pH, manure temperature and air temperature and air velocity over the manure surface (Ye *et al*., 2008; Zhang *et al*., 2008; Saha *et al.*, 2010).

Currently, measurements of ammonia emissions from manure storage systems in field conditions are expensive due to the equipment needed (e.g. nitrogen oxide (NOx) analyser), the manpower and the time-consuming measuring periods (up to 200 days for fattening pigs). Moreover, governments are looking for field measurements in high numbers of livestock buildings and storage systems to implement a policy to reduce ammonia emissions (Vranken et al., 2004; Bluteau, 2009; Hamelin *et al.*, 2010).

The method of ‘‘intermittent measurements’’ was developed for livestock houses and attempts to offer an alternative to the expensive measuring approach by limiting the number of required measuring days (Vranken et al., 2004). With the method of intermittent measurements, the ammonia concentration in a specific animal house is modelled each moment based on an empirical ammonia emission model for an

individual livestock building. This ammonia model calculates the ammonia emission from easily measurable climate variables (indoor temperature, outdoor temperature and ventilation rate) that are continuously available throughout the year from the climate controller in combination with management variables, such as weight and number of animals.

The intermittent method was originally developed in previous studies (Vranken *et al*., 2002) to reduce the high cost of continuous ammonia emission measurements from animal buildings and not from manure storage systems.

The main objectives of this paper are to present a reference technique to monitor the entire emissions from a manure storage tank, and to apply the intermittent measurements approach to estimate ammonia emission from a manure store.

1. MATERIALS AND METHODS:

1.1. Experiment: The experiment was conducted using an experimental storage tank at the National Pig Experimental Station in Romillé, France. The tank was filled with fattening pig manure and totally covered with a cover that was ventilated by a mechanically ventilated system. The tank had a total 13.5 m^3 volume of slurry and the dimensions of the cover are 6 × 3.5 m and ridge height of 2.5 m. The cover was equipped with a fan with a 35 cm diameter, with max ventilation rate of 2600 m^3/h and placed in the upper side of the cover. The experiment occurred for three consecutive months.

1.2. Measurements: Ammonia concentration, ventilation rate, outdoor and indoor air temperatures, indoor air relative humidity, near-manure surface air temperature and humidity, and manure temperatures in different depths (5 cm and 30 cm) were continuously measured. Continuous measurements were taken over the entire slurry storage period (three months) from 22 June 2009 until 15 September 2009.

The ammonia concentration was measured with a photo-acoustic multi-gas monitor (INNOVA 1312) with a 6-channel-multi-sampler. Indoor air samples were taken in the exhaust of the ventilation. Ammonia concentration was measured every 1 hour. A calibrated ventilation rate sensor measured ventilation rates with ±45m^3/h accuracy. Indoor air temperature was measured in the exhaust openings. All variables (ventilation rate, slurry temperature, indoor air temperature, surface air temperature and humidity) were recorded every 15 minutes.

1.3. Intermittent measurements method: In the principles of intermittent measurements method, the expensive field measurements of ammonia emissions are performed for a limited number of measuring days distributed over the whole estimation period. Using the data of these selected days, a simple mathematical model was developed that relates the expensive field measurements of ammonia emission with the continuously measured related variables, such as outside temperature, indoor air temperature, slurry temperature and indoor air relative humidity. This statistical model is used in a following step to estimate the ammonia emission over all other days, using the data of the easily-measured related variables over the whole year. For validation of the procedure, continuous measurements of ammonia emission were used as reference data.

Ammonia emission from the manure storage system can be calculated as a function *f* of number of easy measurable variables as follows:

E=f(near manure surface air temperature, slurry temperature)

Where E is the ammonia emission (g/h)

2. RESULTS AND DISCUSSION:

2.1. Model identification: The correlation coefficient matrix (Table 1) was calculated from the whole measurement period, including the ammonia emission and the related variables, specifically: the indoor air temperature, near slurry surface air temperature, slurry surface temperature, below slurry surface temperature, indoor air temperature, indoor relative humidity, and ventilation rate.

Table 1. Correlation coefficient matrix results from covered slurry storage tank including the ammonia emission and the related variables.

Variables	Correlation coefficients						
	E	u_1	u_2	u_3	u_4	u_5	u_6
Ammonia emission (E)	1						
Near surface air temp. (u_1)	0.88	1					
Surface temp. (u_2)	0.73	0.82	1				
Indoor air temp. (u_3)	0.67	0.90	0.59	1			
Below surface temp. (u_4)	0.41	0.39	0.44	0.18	1		
Indoor humidity (u_5)	0.45	0.58	0.22	0.53	0.11	1	
Ventilation rate (u_6)	0.50	0.32	0.29	0.41	0.19	0.58	1

The matrix showed a high correlation between ammonia emission and several of the proposed related variables. Near slurry surface air temperature, slurry surface temperature u_2 had a strong correlation with ammonia emission E. Therefore, it was judged that at least the variables u_1 and u_2 should be included in the model structure. Using only these two variables, a linear steady-state model structure was defined to predict ammonia emission over the whole measuring period.

The following linear steady-state model structure was used:

$$E=au_1+bu_2+e$$

where E is the ammonia emission $g.h^{-1}$, a and b are the estimated model parameters. For the selected days for modelling, the value of the coefficient of determination R^2 was at least 0.84.

Figure 1 shows an example of using the presented model structure to predict the ammonia emission from a covered storage tank over a period of one month. The model parameters (*a* and *b*) were estimated in which the data of the first five days was used to estimate the model parameters. The resulting linear steady-state model was

used to predict the ammonia emission over the all other days, using only the data of the related variables over the entire time period. For validation of the procedure, continuous measurements of ammonia emission were used as reference data (Figure 1).

The resulting model well-described the ammonia emission from the first five days and had a R^2 of 0.84 (Figure 1.A). Ammonia emission data from the selected day was used later to validate and retune the model parameters (Figure 1.B). The validation results showed that the model parameters did not change significantly (a=0.2386 and b=- 0.0227). The model was used to simulate the ammonia emission from the whole period. The measured ammonia emission from the storage tank for one month was about 3.4 kg and the predicted ammonia emission was about 3.1 kg. The error of the predicted ammonia emission (with 95% certainty under the normal distribution) was greater than 9 %.

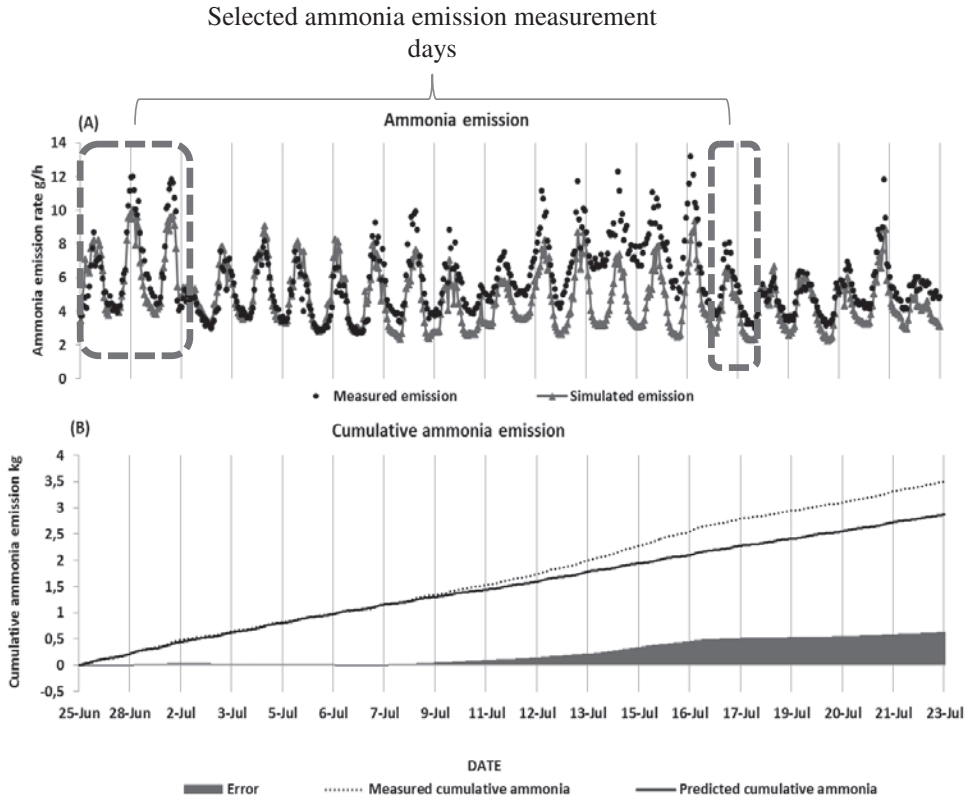

Figure 1. Comparison of measured and simulated ammonia emissions

CONCLUSION: Near surface air temperature and manure surface temperature within the ranges of 12-45°C and 15-32°C, respectively, are sufficient and suitable to model ammonia emission and to estimate the cumulative ammonia emission. The resulting linear steady-state model well-described the ammonia emission from the storage tank for the modelling days with a R^2 of 0.84. The model was suitable to calculate the cumulative ammonia emission (max Error=9%). Ammonia emission data from one day with sampling frequency of 1 sample per hour was sufficient to validate the model

parameters. During these three months of ammonia emission monitoring, the model parameters did not change significantly; however, it is suggested to calibrate/retune the model parameters during the different seasons in the year.

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Part V.
Measuring methods

ROLE OF HOUSING SOLUTIONS IN REDUCING GHG EMISSIONS FROM DAIRY CATTLE FARMS

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ABSTRACT: The atmospheric emissions of CH_4, N_2O, CO_2 and NH_3 from four dairy farms with different dairy cow housing solutions were monitored using the "chamber method" procedure. Results show that the environmental impact of livestock is higher on those farms where manure removal is implemented with a scraper on concrete flooring. The addition of rubber matting in the alleys can improve the cleaning efficiency of scrapers and reduce NH_3 and CH_4 emissions. Lower emissions were observed in dairy houses equipped with slatted floors and/or a flushing system for slurry removal.

Keywords: GHG, N_2O, CH_4, NH_3, CO_2, emissions, housing solution, environmental evaluation, mitigation strategy, dairy cattle, measuring method.

INTRODUCTION: Agricultural practices account for 10 to 12% of the world total GHG emissions; however, this could reach between 17 and 32% (8.5-16.5 Pg CO_2-eq) by including all agriculture-related emission sources (Godbout et al., 2012). GHG emissions from dairy barns can be divided into three main groups: i) CH_4 emissions from cattle enteric fermentation; ii) CH_4 and N_2O emissions due to manure management practices; iii) N_2O emissions from cultivated fields, including direct emissions from crop land and pasture and indirect emissions resulting from the use of nitrogen fertiliser in agriculture. Manure management is responsible for 13% of GHG emissions from the agricultural sector, with CH_4 and N_2O accounting for 33 and 67% of CO_2eq, respectively (Steinfeld et al., 2006). Current trends suggest that this level will substantially increase over the coming decades as the intensification of livestock activities continues. In Italy, dairy cows are responsible for 66.5% of the 17427 Gg of CO_2eq emitted from agriculture. Sommer et al. (2009) report that choosing the proper building solution can reduce overall GHG emissions up to 32% from Italian dairy cattle structures. The aim of this work is to evaluate seasonal emission factors of CH_4, N_2O, CO_2 and NH_3 from different dairy cow housing solutions to provide guidance about farms' environmental impact since the environmental impact of livestock operations cannot be considered negligible, in particular with reference to the global warming potential of CH_4 and N_2O (21 and 310 times over hundred years greater than CO_2).

1. MATERIAL AND METHODS: The emissive flows of different housing solutions were studied using the "chamber-method" (Brewer et al. 1999; Hörning et al. 1999; Dinuccio et al., 2008) by determining the rate of increase in concentration ($\delta C/\delta t$) in a closed truncated pyramidal chamber placed on the emitting surface of the monitored dairy barns (Figure 1). To avoid measurement errors due to gas stratification, the chamber was equipped with a small fan to maintain circulation of the air trapped in the "headspace". NH_3, N_2O, CH_4 and CO_2 were measured by the Infrared Photoacoustic Detector (Bruel & Kjaer, multi gas monitor type 1302) at 2 min interval. The emission factors ($mg/m^2 \cdot h$) were calculated with equation 1:

$$Emission\ factor_{gas}\left[\frac{mg}{m^2 \cdot h}\right] = \frac{\delta C\left[\frac{mg}{m^3}\right]}{\delta t[h]} \cdot \frac{V_{ch}[m^3]}{A_{ch}[m^2]} \quad (1)$$

where $\delta C/\ \delta t$ is the angular coefficient of the regression line of gas saturation function, while V_{ch} and A_{ch} are the volume (0.017 m^3) and the lower base (0.174 m^2) of the truncated pyramidal chamber.

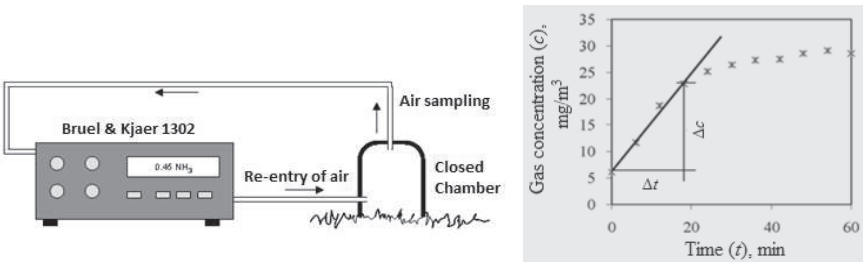

Figure 1. Schematic view of the sampling process (left); gas concentration in the measuring chamber over time (right). The gas flow is measured using equation 1.

Three monitoring campaigns (March-June 2011, October-December 2011 and January-March 2012) were performed on four dairy farms equipped with different flooring and/or slurry removal systems: i) scraper on concrete floor; ii) scraper on rubber mat; iii) slatted floor; iv) flushing system. Such building solutions were chosen since they are the most widely used in the Po valley so that differences in their environmental impact could be delineated. Emission data were acquired from different shed components: feeding alleys and resting area (cubicles equipped with straw, rubber mat or deep litter).

2. RESULTS AND DISCUSSION: Results of measurement trials (Table 1) reveal the feeding area as the major source of NH_3. Here, emission factors reach the highest values during the warm season (over 65.00 mg/m^2·h), since its emission increased with temperature (Pereira et al., 2011). Housing solutions based on concrete flooring and a scraper showed greater emission factors during all periods of the year. Comparisons between dirty and clean surfaces on solid floors demonstrated that the use of scrapers can increase NH_3 emission. This phenomenon was also reported by Sommer et al. (2006), who state that scraping a non-sloping concrete floor has little effect on NH_3 emission because the thin layer of slurry retained by the floor is a significant source of NH_3. According to our data, the use of rubber matting for walking areas could enhance the cleaning efficiency of the scrapers since it reduces floor roughness. Data collected from barns with flushing systems showed a significant reduction in NH_3 emissive potential of feeding lanes.

Regarding N_2O, cubicles and deep litter systems appear as the main sources. Our data confirm a study published by Chadwick et al. (2011), who reported significant N_2O emissions occurring from straw-bedded buildings, suggesting the adoption of slurry-based systems for its mitigation.

CO_2 emission factors are higher from the resting area and, in this first year of monitoring, seem to confirm their temperature-related behaviour.

Concerning CH_4, literature abundantly reports its production during anaerobic degradation of faeces and bedding materials, as well as ways it is affected by temperature, biomass composition, manure management and removal frequencies (Sommer et al., 2009; Chadwick et al., 2011; Nardone et al. 2011). Data collected

from slatted floor units validate this, as the recorded CH_4 emissions are higher from slatted floor systems, while the opposite behaviour is shown by emission factors from housing systems with flushing removal equipment. This is probably due to the permanence of manure underneath concrete perforate elements. Nevertheless, the emission factor of 97.1±7.80 mg/m^2·h registered from the clean concrete alley does not correspond to the above mentioned findings. This can be explained by the peculiar surface of the floor, which is provided with several longitudinal grooves to prevent cattle from slipping. These grooves entrap manure at the passage of the scraper, causing it to anaerobically ferment in the deeper parts of the grooves. Another source of CH_4 seems to be the cubicles: their cleaning condition can seriously affect this datum.

Table 1. Seasonal emission factors of monitored gases from different dairy farms.

	Point of sample			Emission factor of gas [mg/m^2·h] (mean ± standard error)			
			°C	NH_3	N_2O	CO_2	CH_4
Spring	Scraper on concrete floor	dirty	14	70.70±4.54*	0.32±0.11*	1302.20±257.20*	17.90±4.10*
		clean	14	64.40±3.70*	0.15±0.06*	480.00±115.00*	97.10±7.80*
	Scraper on rubber mat	dirty	14	68.40±21.70*	0.40±0.10*	927.80±143.80*	10.00±2.10*
		clean	14	23.03±1.20*	0.14±0.02*	456.40±113.60*	7.33±0.91*
	Slatted floor		16	15.80±5.80*	0.14±0.08*	563.70±288.90*	23.80±14.50*
	Flushing system		17	14.10±3.50*	0.02±0.01*	495.80±178.20*	12.30±4.70*
	Cubicles	straw	21	1.58±0.35*	1.20±0.27*	2040.20±347.30*	45.60±7.50*
		rubber mat	14	2.20±0.60*	0.10±0.08*	48.80±22.90*	7.90±4.34*
	Deep litter		21	23.40±3.05*	1.23±0.26*	2814.00±396.00*	4.76±0.22*
Autumn	Scraper on concrete floor	dirty	-1	6.39±0.67*	0.23±0.03*	600.13±9.64*	0.49±0.14
		clean	-1	27.96±4.79*	0.16±0.02*	339.64±3.18*	0.73±0.25
	Scraper on rubber mat	dirty	3	6.60±1.01*	0.42±0.11*	459.19±127.59*	3.93±0.48*
		clean	3	12.76±1.72*	0.10±0.05	459.85±262.06	-**
	Slatted floor		2	4.74±1.02*	0.45±0.06*	1460.79±120.47*	7.71±1.20*
	Flushing system		2	0.34±0.01*	0.05±0.01	13.83±8.42	0.88±0.29
	Cubicles	straw	-1	0.57±0.73	1.73±0.07*	2696.34±170.47*	3.65±0.49*
		rubber mat	3	2.68±0.25*	2.41±0.17*	3414.48±381.39*	98.93±19.22*
	Deep litter		-1	4.24±0.64*	0.97±0.23	1642.76±444.59	-**
Winter	Scraper on concrete floor	dirty	4	12.4±2.64*	0.17±0.06*	641.82±59.36*	1.85±0.17*
		clean	4	3.51±0.31*	0.18±0.02*	567.55±91.09*	3.42±0.76*
	Scraper on rubber mat	dirty	10	33.01±10.17*	0.06±0.15	412.67±226.32	5.31±0.27*
		clean	10	24.60±2.48*	0.24±0.05*	914.42±140.14*	3.10±0.05*
	Slatted floor		9	19.26±8.11	0.11±0.05	274.02±165.17	27.58±3.89
	Flushing system		10	0.38±0.13*	0.04±0.01	99.83±10.89*	0.59±0.12*
	Cubicles	straw	4	-**	2.96±0.60*	3079.24±423.60*	-**
		rubber mat	10	-**	6.00±0.51*	7291.17±834.76*	178.56±45.59
	Deep litter		8	3.98±0.81	3.86±0.85	5255.39±1067.89*	73.52±10.82*

*P <0.05; **data not available.

CONCLUSION: The results of the first year of monitoring trials confirm the direct relationship between temperature and emission of NH_3 and CH_4. Results also underline the current high environmental impact of livestock farms regarding manure removal implemented with a scraper on solid concrete flooring. The use of rubber

mats can slightly increase the scraper's cleaning action with subsequent mitigation of the emissive potential of the alleys. The resting area is the major source of N_2O and CO_2 emissions, while NH_3 is released mainly from the feeding area. Lower emissions were observed in barns equipped with slatted flooring and a flushing system for slurry removal. These provisory indications could be useful for agricultural engineers in setting up new strategies which can help farmers of the Po valley switch from ordinary practices to more sustainable livestock farming.

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MEASUREMENT OF AMMONIA EMISSIONS ON A POULTRY FARM WITH LAYING HENS LOCATED IN A SEMI-ARID REGION (NORTHEAST ALGERIA)

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ABSTRACT: The present study concerns the ammonia produced by droppings found in the pits under the batteries on a poultry farm. It has helped determine the concentration of ammonia emitted inside such buildings.
The experiment was performed in Northeast Algeria. It occurred on a poultry farm with laying hens kept in conventional coops with a breeding capacity of about 14,400 hens. The study is divided into two experiments.
The first experiment consists of a remote control method intended to trap the ammonia, which required special equipment to run alongside the pit situated in the middle of the building, and placed 50cm above the droppings. The results obtained from this first experiment revealed that the concentration of ammonia ranged from 1.12 to 4.49 ppm.
The second experiment consists of trapping ammonia in close contact with the droppings and measuring the amount of ammonia emitted in a precise area. In this experiment, ammonia concentration varied between 0.81 and 14.25 ppm.The results obtained in the two experiments correspond with those published in special publications (Aloui,N.et al., 2001); (Hinz.T.et al., 1998); (Miehel .V. et al.,2007).
The principle governing our experiment consists of trapping the emitted ammonia by bubbling air sucked by a pump into an acid solution (HCl). This method was based on Rognon.C.et al. (2010) and Roustan, M. (2004). The two experiments considered whether the droppings in the pits were previously scraped.

Keywords: ammonia, poultry farm, hens, semi-arid region, Northeast Algeria

INTRODUCTION: To evaluate the effects of agricultural practices on air quality requires knowing the principal atmospheric pollutions emitted. These are various and depend on the kind of farming and on specific farming methods. An inventory of all categories of polluting gas emissions revealed the extent the agricultural sector remains predominant concerning emissions of the following three gases: CH_4, N_2O, and NH_3 (CORPEN., 2006) ; (Phillips.V.R.et al.,1997). Among those responsible for acidification and eutrophication of the environment, ammonia rates highest (Schulte.D,1997). Knowing the greatest part of the anthropogenic emissions of this gas: about 94% are linked to agriculture and 68% are related to farming activities (Steinfeld.H. et al., 2006), particularly to poultry farming. According to the kind of poultry farming involved, there is variation in the nature of manure and, as a consequence, a fluctuation in the amounts of ammonia emitted. The quantity of droppings produced depends on several parameters: speculation and species, foods, the weight of individual animals, the lifespan of the breeding of animals and the type of breeding used (Znaidi.I.A. 2002).

The aim of this study consists of measuring ammonia concentrations on a poultry farm building containing laying hens to determine the ammonia concentration in the different parts of the building.

1. MATERIAL AND METHODS:

1.1. Battery-reared laying hens: The experiment was performed on a poultry farm containing 14,400 Hy-line laying hens. The hens are raised inside three A-shaped batteries containing 4 hens per cage. The building is equipped with four air extractors situated at the end of the building and with two humidifiers situated between two side walls (Fig1).

The composition of the feed consists of the following products: 60% maize, 20% soya, 1.5% CMV (supplementary benefit mineral and vitamins), 10% rough bran, 7% limestone and 5% Phosphate bi calcic

1.2. Statistical study: For our study, we recorded the concentration of NH_3 for such measurements and applied the variance analysis using "Minitab" software, and considered that our work was performed with devices that are completely rudimentary.

1.3. Measuring ammonia: The working principles of the devices used to measure ammonia can be similar. During the tests (National Academy of Sciences.. 2006) and (Roadman.M.J.,2003),the description of the devices used, respectively, "Ion chromatography" and "Ogawa passive samplers", mentions the presence of several filters, one a reactive filter soaked with citric acid. Several acids, among them sulphuric acid, phosphoric acid, oxalic acid, can be used for the absorption of NH_3 (Roadman.M.J.,2003). Other principals can be used, such as gas washing by means of absorption. The absorption here consists of matter transfer from a gaseous phase into a liquid phase, with the polluting element present in the air turning a soluble into a liquid. The washing solutions of the air used to capture ammonia are acid solutions and are mainly based on hydrochloric or sulphuric acid. These generate immediate surface reaction (Roustan. M., 2004).

To begin our experiment, we trapped ammonia by spraying the air surrounding the pits, or just directly above the droppings, with an acid solution. The surrounding air is sucked by a pump and then drained via a pipe towards the acid solution. Into this solution, hydrochloric acid of a weak concentration type (10^{-5} N), a few drops of methyl red were added. A color change from light red to light yellow indicates that the solution is saturated with ammonia. This catchment of ammonia present in the air occurred according to two methods:

1.3.1. The catchment of ammonia using a remote control: This method consists of trapping the air with pumps hanging above the pits at about 50cm above the droppings. The frequency is one measurement per day for 9 days, which amounts to nine tests performed in all. The experimental mechanism uses four separate air sensors, each one equipped with a sucking force pipe (Champion CX-0078, Aquarium Air Pump - Air output 0078C.C/min). The air sucked by each pump is forced into the colored hydrochloric acid solution contained in 2.25 l bottles (Fig 2). These four sensors are placed along the pit under the battery situated in the middle, as shown in (Fig 1):

- The first sensor is placed 10m away from the start of the pit in front of the building.
- The second sensor is placed 20m away from the first sensor.
- The third sensor is placed 20m away from the second sensor.
- The fourth sensor is placed 20m away from the third sensor and 10m from the end of the pit.

The experiment begins when the pumps are activated. The time necessary for the color change of the solution is recorded. For each test, 3 measurements were performed for each catchment point.

1.3.2. Catchment of ammonia in direct contact with the droppings: This method captures the air using sensors placed directly on the droppings before scraping. This quantifies the ammonia emitted from a particular area covered with droppings. This occurs for four weeks, with one measurement per week totaling four tests. The sensor used in this experiment is a rectangular-shaped tank containing a pump, similar to the one used above. The pump is fixed in the middle of the tank and is connected by a 5mm diameter pipe (Fig. 3) to a bottle containing a hydrochloric acid solution (HCL) at 10^{-5}N. The tank is then turned upide down to delimit a specific area covered with droppings and, consequently, the air emitted is sucked by the pump. For each test, the four sensors are placed in close contact with the droppings at about 1.5m from the start of the pits (Fig 1).

Three measurements per sensor were taken during each test. The splashing time of the air before the color change of the solution was recorded.

The setting of the four sensors is changed after each test (Tab1) to determine the changes in ammonia concentration, according to the measurements points: in front of or behind the building, according to the pits.

Table 1. Positions of the sensors according to the pits in different tests.

Pits	Position of the sensors according to the pits	Test 1	Test 2	Test 3	Test 4
Left	front		+	+	
	back	+	+		+
Middle	front	+		+	+
	back	+		+	+
Right	front	+	+		
	back		+	+	+

During the four tests, the three fittings were kept in the same condition, i.e. not scraped before the end the samples for measurement, and were taken out at 8 am each time.

1.3.3. Calculation of ammonia concentration: Including that the resolution used to capture ammonia prevailing in the air is a hydrochloric acid solution HCl of volume V_{HCl}, equal to 0.25l and normality equal to 10^{-5}N, when the color of the solution changed, the number of moles n_{HCl} is neutralized by an equal number of moles, n_{NH3}, of NH_3, present in the volume of air having bubbled in the solution. Therefore, we can deduce that:

$$n_{NH3} = n_{Hcl} = 0{,}25 * 10^{-5} \text{ mole de } NH_3. \quad (1)$$

As it is admitted that NH_3 is a perfect gas, the number of moles n_{NH3} of NH_3 per liter is as follows:

$$0{,}25 .10^{-5} \text{ mole de } NH_3 * 22{,}4\text{l} = 5{,}6 .10^{-5} \text{ mole /l} = 5{,}61. 10^{-2} \text{ mole /ml.} \quad (2)$$

To obtain the volume concentration, □, of ammonia in ppm present in the prevailing air, we calculate the ratio between the number of moles, n_{NH3}, of NH_3 per milliliter and the air volume ,V, having bubbled , during a specific time t, in cubic meter m^3.

2. RESULTS AND DISCUSSION:

2.1. Ammonia catching from a distance: For this experiment, the ammonia emissions stand between 1.12 and 4.49 ppm. This interval includes the two series of tests, the one before scraping the pits, in which the ammonia values vary from 1.54 to 4.49 ppm, and the other after scraping, which the ammonia values vary from 1.12 to 4.08 ppm(Fig 4).

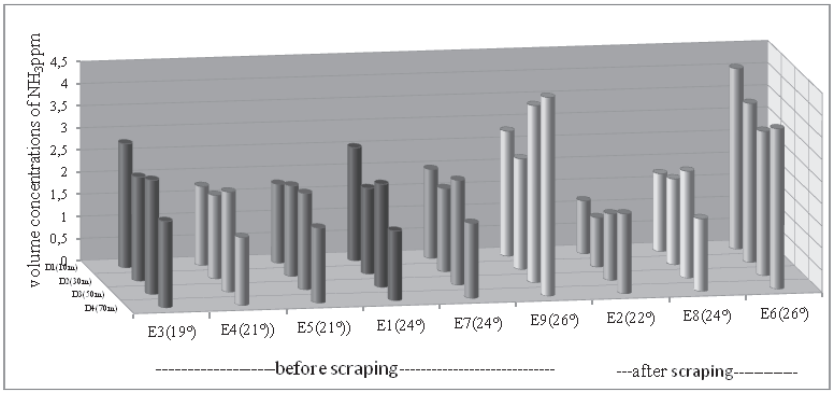

Figure 1. Variations of volume concentrations of NH_3 according to the temperature, before and after scraping of excrement.

These values are consistent with those mentioned in specialized publications and stand in an interval between 1 and 20 ppm. The values obtained by Hinz.T. et al, (1998) are 20 ppm and can reach 50ppm. Values vary from 0.16 to 31.2 ppm for Aloui,N et al, (2001), from 1.5 to 4.2 ppm for Miehel. V.et al. (2007) and from 1.6 to 67.1 ppm for Groot Koerkamp. P.W.G., et al,(1998). Even if our results are considered as within the same interval as those mentioned in publications, they can be considered as rather weak when we consider that such results were obtained at 50 cm above the droppings, and not from tests inside the building itself, as is the case concerning the values mentioned in other publications.

As the composition of effluents depends on the conversion rate of nitrogen present in meat, it thus indirectly depends on the animals' age, weight as well as species, (EEA.1999) in (Fabbri.C. et al,1998).

Additionally, ammonia emissions depend on the droppings' composition, which is attributed to protein types and, consequently, to amino acid types within the food consumed (Leclerq.b. , 1996). Emissions coming from droppings are greatly influenced by the amount of volatile solid matter, availability of oxygen (aerobic or anaerobic), temperature, ph, and the period of time droppings are stored (O'neill,D.H. et al., 1992). All these differences can affect our results.

To augment the potency of our test, we considered the medium values of the volume concentrations obtained by the four censors for each test. Analysis of these medium values' variance revealed two groups of homogeneous medium results. The first group corresponds to test n°9, before scraping the pit, and to test N°6, after scrapping.

Both tests were performed under the same temperature of 26 °C. The second group comes from the other medium results obtained during the rest of the tests under temperatures ranging between 19° and 24°C, regardless of the pits being scraped.
According to publications, as the temperature increases ammonia emissions decrease because they are evacuated by ventilation inside the building (Barbault, R., 2003). However, our results do not indicate this, which is certainly due to recording occurring 50cm directly above the droppings. The ventilation is; therefore, inadequate for efficient evacuation.
Our results can be justified by such differences. From these results, we can state that volume concentrations of NH_3 vary along the pit for each test. The highest values were obtained under a 26°C temperature. There are no significant differences between the average results of the medium volume concentrations of the tests below temperatures of 26°C.

2.2. Catching ammonium in direct contact with droppings: The differences between test results revealed that the medium volume concentrations of ammonia are not the same in different locations of the building. The results recorded are higher in the far end of the building than in the front. They range between 0.81 and 14.25 ppm for the 4 tests. (Figure 5).

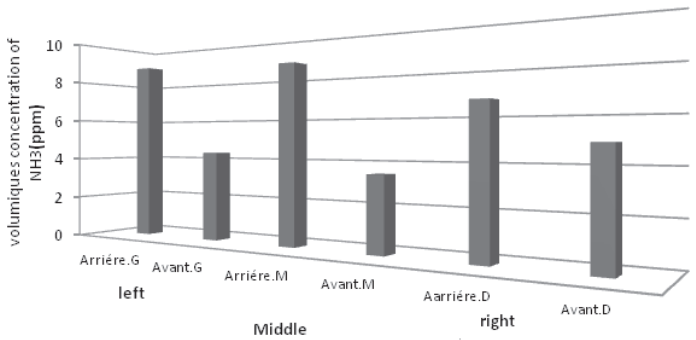

Figure 2. Variation averages of volume concentrations of NH_3 (ppm).

It is noted that our results are closely connected with a specific surface area of 0.38 m^2. From this, it may be deduced that the ammonia emissions results varied between 2.13 ppm/m^2 and 37.5 ppmm^2 (Figure 5).

In this experiment, the values of obtained volume concentrations are higher than those recorded in the previous experiment 50 cm above the droppings. The medium ammonia concentrations recorded are consistent with those mentioned in publications [(Barbault. R., 2003) ; (CORPEN., 2006); (Aloui,N et al., 2001);(National Academy of Sciences; 2006)].
If the medium volume concentrations are higher in the far end of the building, this is certainly due to the extractors' combined effect of aspirating the prevailing air in the building towards the back with the evacuation opening of the droppings situated at the bottom of the left wall behind the building, where droppings are heaped before removal.

CONCLUSION: This study enabled the measurement of ammonia volume concentrations on a poultry farm. The concentrations vary in the interval 1.12 to 4.49

ppm at a distance of 50 cm above the droppings and between 0.81 to 14.25 ppm during the recordings performed in direct contact with the droppings.

When the measures were verified, at 50 cm above the droppings, no significant differences appeared between the measures performed before and after scraping with temperatures below 26 °C. For the tests performed in direct contact with the droppings, the concentration increases from the front of the building into the far end, particularly on the left side of the building. The ammonia volume concentration rises as the temperature increases in both experiments.

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APPENDIX:

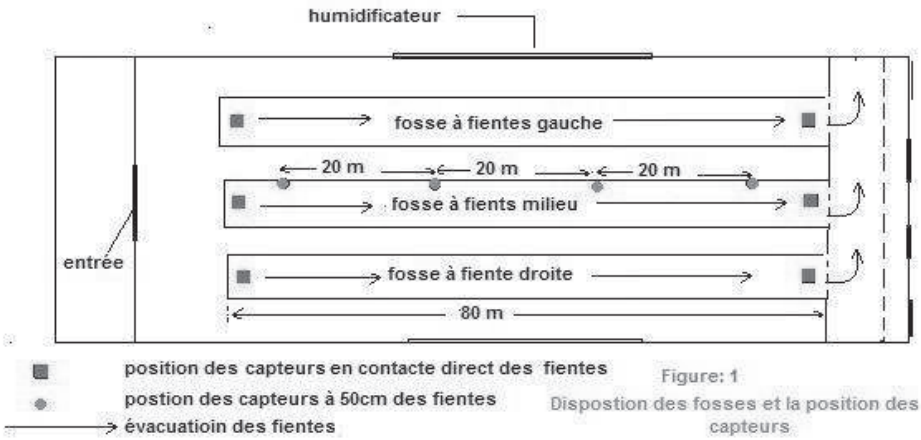

Figure: 1
Dispostion des fosses et la position des capteurs

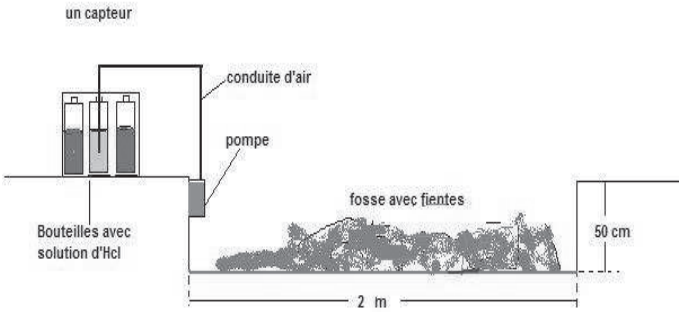

Figure n°2: Capteur au bord de la fosse

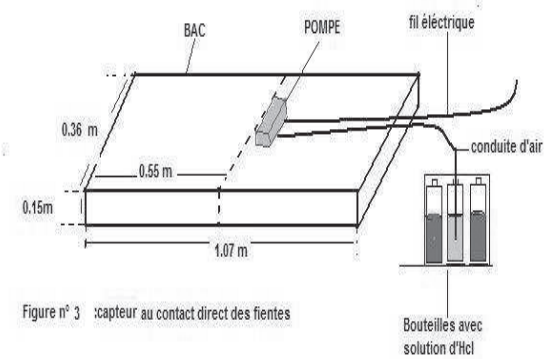

Figure n° 3 :capteur au contact direct des fientes

ORGANIC WASTE ODOUR CONTROL WITH STATE-OF-THE-ART OLFACTOMETRY

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ABSTRACT: Higher living standards, a more stressful lifestyle and closer proximity between residents and odour sources have increased public awareness towards odours, whether pleasant or unpleasant. Still, in the 21st century no instrument can replicate the human perception of odours because of the synergetic effect generated among its constituting gases. Therefore, olfactometry is the science of measuring the odour dilution threshold, hedonic tone and intensity, using trained panellists within a setup designed for unbiased evaluation. The science of olfactometry has evolved since its beginnings in the early 1970's and currently several official detailed guidelines are available in Europe (CEN 13725 and VDI 3882) and North America (ASTM 679). The present paper will present: 1) a state-of-the-art olfactometer designed to meet European and North American guidelines, and to provide comfort to its panellists for more consistent results, and; 2) applications of olfactometry.
A state-of-the-art olfactometer in operation at Consumaj, in St Hyacinthe, Canada, was designed to respect European and North American guidelines. Specifically, the Consumaj olfactometer offers a nonagon (9 sided) shape which can accommodate up to 16 panellists to meet the German VDI 3882 guidelines. The dilution of odorous samples is performed using air flow meters rather than set venturi openings for more flexibility in selecting the range of dilution levels. The ergonomic features of the Consumaj olfactometer will be described, such as panellist air sampler angle and seat height. One application of olfactometry will be demonstrated: the modelling of odour emissions from a poultry farm. Field odour plume evaluations using trained panellist will be compared to modelling results. Furthermore, the presentation will demonstrate the effect of applying attenuation technologies on odour plume extent as a function of local climatic conditions.

Keywords: olfactometer, odour measurement, odour dispersion, modelling

INTRODUCTION: Higher living standards, a more stressful lifestyle and closer proximity between residents and odour sources have increased public awareness towards odours, whether pleasant or unpleasant. Still, in the 21st century no instrument can replicate the human perception of odours because of the synergetic effect generated among its constituting gases. Therefore, the science of olfactometry or of measuring the odour dilution threshold, hedonic tone and intensity by using trained panellists has greatly evolved, especially within a setup designed for unbiased evaluation. The science of olfactometry has evolved since its beginnings in the early 1970's and currently several official detailed guidelines are available in Europe (CEN 13725 and VDI 3882) and North America (ASTM 679). The present paper will present: 1) a state-of-the-art olfactometer designed to meet European and North American guidelines, and to provide comfort to its panellists for more consistent results (Figure 1), and 2) applications of olfactometry.

The present paper describes a state-of-the-art olfactometer now in operation at Consumaj, in St Hyacinthe, Canada, along with its ergonomic features providing and

respecting European and North American guidelines. One application of olfactometry will be demonstrated: the modelling of odour emissions from a poultry farm.

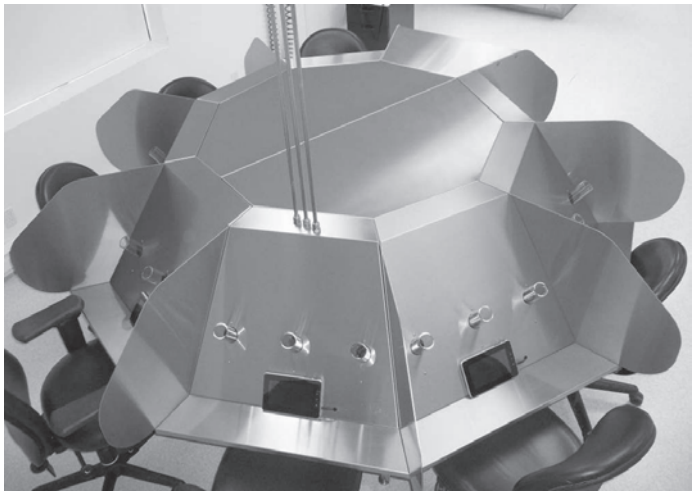

Figure 1. The nine-sided dynamic olfactometer developed by Consumaj inc.

1. PRESENTATION OF THE OLFACTOMETER: It is generally known that an odour is subjective and its perception may vary from one person to another. This is true when examining the appreciation an odour, which may vary from one person to another. However, an odour can be objectively quantified by following a scientific method. The science dealing with the characterization of an odour is named olfactometry and is regulated by international guidelines for the standardization of the analytical method and of the result presentation. The main tool used for analysis of odorous emissions is a dynamic olfactometer and it allows, among other features, the determination of the odour threshold dilution or the dilution at which an odour emission is detected by 50% of the panellists. To eliminate bias, the dynamic olfactometer presents three air flow sniffing ports to each panellist, one of which is contaminated with the odorous sample. The panellists must determine which port is contaminated.

Accordingly, the following procedure is used during the olfactometer determination of an odour threshold dilution. The panellists are selected using an n-butanol detection scale: the very sensitive and non-sensitive panellists are eliminated to remove extreme responses. Then, panellists are trained according to the EN 17325 guidelines and are required to consistently detect the air flow port, among three, which is contaminated with the odour sample. A diluted odour sample is brought to one of the sniffing ports while fresh air is brought to the two other ports. The odour is randomly sent to a different port between each presentation. This procedure is called the 3-way forced-choice odour detection method.

The panellists are first presented the odour sample diluted to the extent that no one can detect the contaminated port. The concentration of the odour sample is increased between presentations until all panellists can detect the contaminated sniffing port twice in a row. The olfactometer data is then used to calculate the odour threshold dilution according to the selected standard, which generally corresponds to 50% of the

panellists correctly detecting the contaminated port. The dynamic olfactometer can also present the panellists with a stronger concentration of the odour sample to evaluate its character, such as hedonic tone and strength.

The nine-sided olfactometer designed by Consumaj in 2011 is ergonomic and can accommodate up to 16 panellists to respect the German VDI3882 guideline. The ergonomic features of the olfactometer consists of a comfortable angle for the sniffing ports, the table allowing panellists to rest their arms during the process, and the easy-to-use touch screen consoles used for recording the results. These features help to keep the panellist attentive and alert and reduce fatigue during odour analysis sessions.

Once all the data is recorded, an odour analysis is performed to calculate its dilution threshold. By definition, the odour dilution threshold is achieved when 50% of the panellists can detect the odour, and it represents the odour concentration of the sample. This odour dilution level is also represented as a concentration or odour unit per cubic meter (o.u/m^3). For example, if the threshold required a 500 fold dilution of the odour sample, then the odour sample concentration is said to be 500 o.u/m^3.

2. APPLICATION OF ODOUR DISPERSION MODELLING: Larger cities and more concentrated agricultural activities have narrowed the gap between urban and rural citizens. While in general, urban citizens and the agricultural community enjoy a friendly relationship, sometimes this proximity creates friction, especially when odour emissions are involved. Odour dispersion modelling can thus be used to determine which control practice can address the issue.

The following example demonstrated the use of air dispersion models in identifying and solving odorous emissions from a poultry farm located close to an urban area. The odour emission rate must first be determined by: 1) collecting samples at the exhaust fans, the principle source of odour in this case, and determining their concentration in o.u./m^3, and; multiplying this concentration by the exhaust fan flow rate in m^3/s, to obtain an odour emission rate in o.u./s. This odour emission rate is thus fed into the dispersion model along with the climatic data for the region, the topography, the poultry barn size and fan locations. The modelling results determine the urban zone affected by the poultry farm odours and the exposure level (ex. 2 o.u.) of this zone.

Figure 2 presents the modelled odour plume generated by the poultry barn. Odour concentrations (o.u.), consisting of different colored contour lines, represent the maximum odour occurring during 98% of the time. This means that during 98% of the time, for a specific location, the odour concentration is lower or equal to that represented, and it can be higher only 2% of the time. The impact of applying a specific odour- reducing technology can also be determined by modelling the dispersion a second time using lower odour concentrations at the fans.

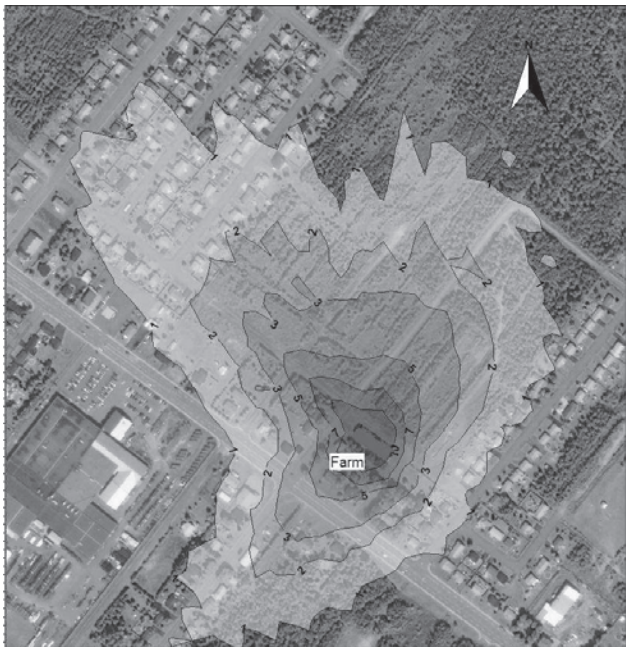

Figure 2. Modelling the odour plume emitted by a poultry farm during 98% of the time.

CONCLUSION: Olfactometry is a relatively recent science that has many applications in the management of odours generated by the livestock industry. The key instrument used for odour analysis is a dynamic olfactometer, such as that developed by Consumaj. The Consumaj olfactometer combines analytical precision and accuracy with ergonomic and easy-to-use features. When combined with air dispersion modelling, a dynamic olfactometer can become a powerful tool to determine the extent of an odour issue, and the treatment required to solve the issue.

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ENVIRONMENTAL RISK FROM DIGESTED MANURE IN RELATION TO THEIR PATHOGEN CONTENT AND GASEOUS EMISSIONS

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ABSTRACT: The primary objective of this study was to measure levels of ammonia and GHG emitted by pig and cattle manure samples before and after the anaerobic digestion process. Concurrently, to study the effect of anaerobic digestion on microorganisms' survival in manure, emission measurements were performed together with microbiological essays to determine the microbial load (E. Coli O157 for bovine samples, Coliforms, Salmonella Species, Sulphite Reducing Anaerobes, Enterococci and Lactobacilli) in manure samples before and after treatment at different sampling times. Samples were taken before and after manure treatment: in the reception pit and after the digestion process. In the laboratory, 0.2 l of each sample was placed in a tank to measure gaseous emissions through the dynamic chamber method, using an infrared photo-acoustic detector IPD (Brüel & Kjaer, Multi-gas Monitor Type 1302), while collecting data every minute. These preliminary results highlight the efficacy of digestion treatment on bacteria abatement. Pathogens in cattle slurry were investigated, except for sulphite-reducing anaerobic bacteria (Clostridia) that, in some cases, were enhanced by anaerobic digestion (up to +41 %) and did not survive anaerobic digestion. Ammonia emission increased (up to +130 %) in cattle digested manure in comparison to fresh slurry. Carbon dioxide declined (-16 %) and, as expected, methane emission was considerably reduced (-82%) by the anaerobic treatment. The current study is still in process, the expected results are to find a relation between ammonia, GHG emissions and microbial load before and after anaerobic digestion.

Keywords: ammonia, GHG, emissions, manure, anaerobic digestion, microbial load

INTRODUCTION: Animal manure is well-known to contain pathogenic bacteria that may be a health risk for both humans and animals (Kowal, 1985). In general, land application is a critical practice in manure management for the induced environmental impact. Pathogens from animal waste can threaten humans who have direct contact with manure, or, indirectly consume food or water contaminated with infectious manure. There is a higher risk of pathogen transfer to the food chain when fresh manure is land-applied than when stored manure is land-applied because there is no storage or treatment period to decrease pathogen numbers (Kirk, 2009). Anaerobic digestion by biogas plants is an alternative way to handle animal manure, which leads to greenhouse gas emission reduction and to the production of a fertilizer that may be spread on agricultural land with limited risk for human health.

The aim of this study was to measure levels of ammonia and GHG emitted by pig and cattle manure samples before and after the anaerobic digestion process. To study the effect of anaerobic digestion on microorganisms' survival in manure, the emission measurements were performed together with microbiological essays to determine the

microbial load (E. Coli O157, just for bovine samples, Coliforms, Salmonella species, Sulphite Reducing Anaerobes, Enterococci and Lactobacilli) in manure samples before and after treatment at different sampling times.

1. MATERIAL AND METHODS:

1.1. Manure sampling: Manure samples were collected before and after anaerobic digestion on 4 farms, 2 piggeries and 2 dairy farms. Digestion temperatures were 37°C for Pig Farm 1 (40 d of retention, HRT), 43°C for Pig Farm 2 (56 d HRT), 48-50 °C for both dairy farms (respectively, 90 and 100 d HRT).

1.2. Microbiological essays: Microbiological essays were performed to determine the microbial load (E. Coli O157 for bovine samples, Coliforms, Salmonella Species, Sulphite Reducing Anaerobes, Enterococci and Lactobacilli) in manure samples before and after treatment at different sampling times. Samples were taken before and after manure treatment: in the reception pit and after the digestion process.

1.3. Chemical analysis: From each slurry sample the following parameters were measured: pH, DM, Total Nitrogen, N-NH_4, Phosphorus content, VFA (as acetate)

1.3. Gas emission measurements: In the laboratory, 0.2 l of each sample was placed in a tank to measure gaseous emissions through the dynamic chamber method, using an infrared photo-acoustic detector IPD (Brüel & Kjaer, Multi-gas Monitor Type 1302), while collecting data every minute for 30 minutes per every sample.

1.4 Statistical analysis: Statistical analysis of the data was performed using SAS statistical software (2008) to evaluate mean values of microbial loads and emission rates as affected by the anaerobic digestion process (GLM Procedure of SAS statistical package, SAS 9.2, 2011).

2. RESULTS AND DISCUSSION:

2.1. Bacterial counts: The following Tables (1, 2, 3 and 4) report the bacterial counts regarding Coliforms, Streptococci, Lactobacilli and Sulphite Reducing Anaerobes. The bacterial analysis revealed that all the manure samples were Salmonella species - free, E. Coli O 157 was not detected in cattle slurries.^

These preliminary results highlight the efficacy of digestion treatment on bacteria abatement ($P<0.01$), in agreement with a study by Harrison et al., 2005. Coliforms were completely reduced in cattle slurries by anaerobic digestion, but not in pig manure, probably because of the high temperature of the digestion process adopted on both dairy farms ($P<0.01$).
Pathogens in cattle slurry were investigated, except for sulphite-reducing anaerobic bacteria. Clostridia that were enhanced in cattle Farm 1 by the anaerobic digestion (up to +41 %) were reduced by the anaerobic digestion.

2.2. Gaseous emission from samples: In general, as mean values, ammonia emission increased (up to +130 %, $P<0.01$) in cattle digested manure in comparison with fresh slurry, carbon dioxide declined (-16 %) and, as expected, methane emission was, in general, considerably reduced (up to -82 %) by the anaerobic treatment.

Figure 5 and 6 show specific examples of gaseous emissions from cattle and pig manure samples.

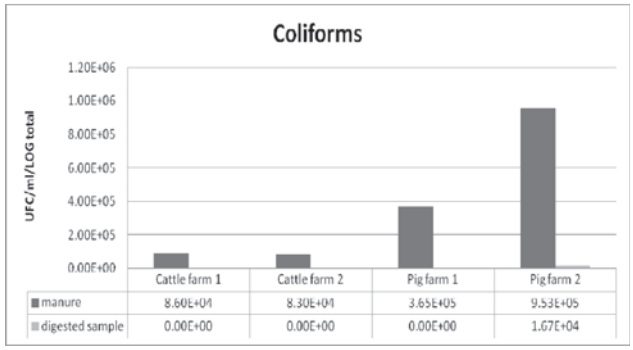

Figure 1. Coliforms counts in cattle and pig.

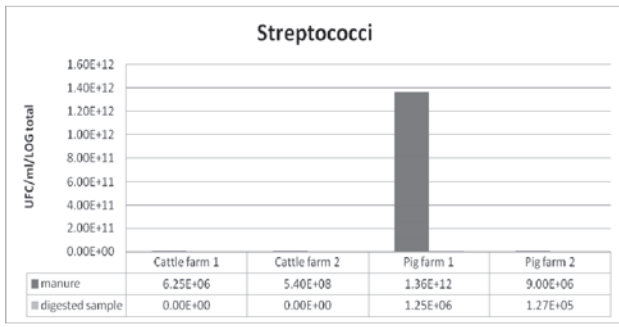

Figure 2. Streptococci counts in cattle and pig.

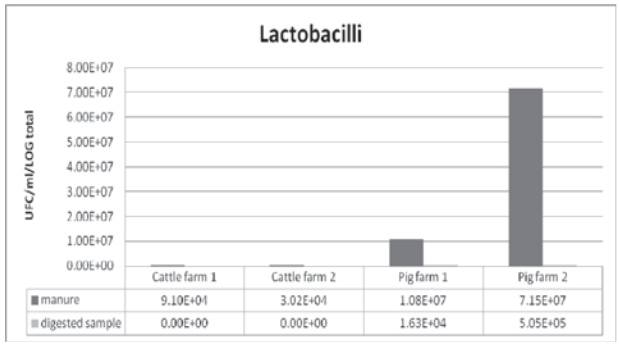

Figure 3. Lactobacilli counts in cattle and pig.

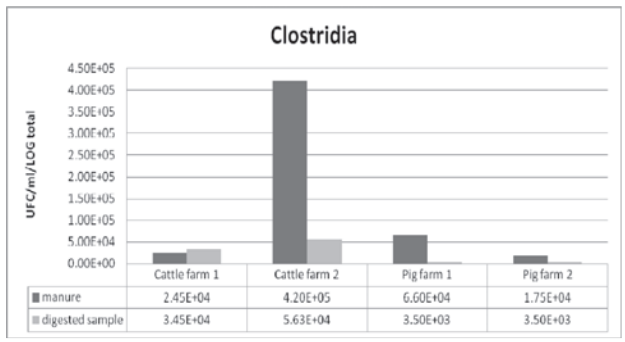

Figure 4. Clostridia counts in cattle and pig.

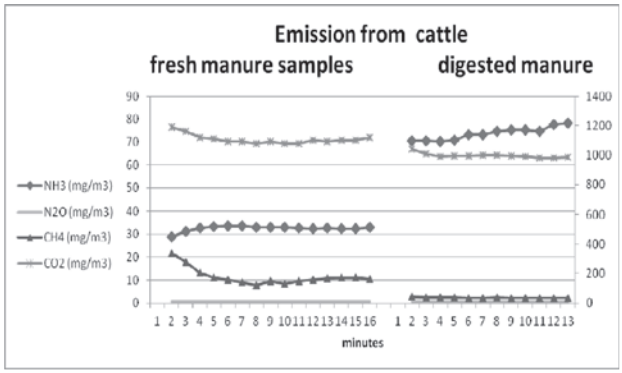

Figure 5. Example of gaseous emission of ammonia, Nitrous oxide, Methane and Carbon dioxide from manure samples before and after anaerobic digestion in cattle slurry, CO_2 scale on the secondary vertical axis.

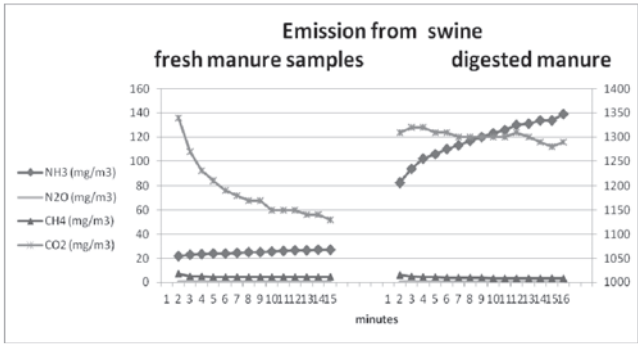

Figure 6. Example of gaseous emission of ammonia, Nitrous oxide, Methane and Carbon dioxide from manure samples before and after anaerobic digestion in pig slurry, CO_2 scale on the secondary vertical axis.

CONCLUSION: The current study is still in process, the expected results are to find a relation between ammonia, GHG emissions and microbial load before and after anaerobic digestion.

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GASEOUS EMISSIONS DURING PIG SLURRY STORAGE: LESSONS FOR FARM MEASUREMENTS

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ABSTRACT: To improve the accuracy of national inventories in France, it is necessary to obtain references on gaseous emissions from commercial pig farms since current emission factors used in France are governed by foreign data. External slurry storage is becoming increasingly important in slurry management because of the increasing frequency of slurry removal from buildings. Gaseous emissions are difficult to measure during outdoor storage because they depend on weather conditions. The objective of this study was to identify a measurement method for external slurry storage for use on commercial farms. Slurry from fattening pigs was stored in a 250-m^3 pit during two periods of the year between spreading operations. A dynamic floating tunnel was used with a photoacoustic infrared gas analyzer to continuously measure ammonia (NH_3), nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2) emissions (Hassouna et al., 2010). Mass balances for water, nitrogen, carbon, phosphorus and potassium were calculated to validate the emissions. Different methods of slurry sampling were tested to explore the possibility of using N and C deficits of the mass balance to deduce gaseous emissions (Robin et al., 2010). The variability in the mass balance deficits revealed that mass balance calculations are not accurate enough to be used to deduce gaseous emissions during pig slurry storage. Measurements of gaseous emissions with the dynamic tunnel seemed the best method.

Keywords: ammonia, nitrous oxide, methane, gaseous emissions, dynamic flux chamber, methodology, slurry storage

INTRODUCTION: Gaseous emission factors for French pig production must improve. Current references used in the national inventory or in environmental assessment of pig production (e.g. LCA) come mostly from other countries, which have different production systems and climate conditions. Due to the application of mitigation strategies, external slurry storage between slurry production and spreading is becoming more important. The best available techniques of manure management performed by farmers, (e.g. gravity removal, flushing) reduce the storage time of slurry in buildings. The periods of spreading also tend to be reduced to prevent nitrogen losses. As a result, manure is externally stored for a longer period of time, rendering gaseous emission measurement more difficult. The most representative slurry storage conditions in France occur in uncovered concrete pits located above the floor that are regularly filled and subject to weather conditions (temperature, rainfall). This study aims to analyze how emission factors (for ammonia and greenhouse gases) can be measured in such livestock conditions and what lessons can be learned when measurements are taken on farms.

1. MATERIAL AND METHODS: The experiment was conducted at IFIP's experimental farm in Romillé (Brittany, France). Two pig slurry storage periods were followed in a 300-m^3 outside pit (5.7-m radius): period 1 from September 2010 to February 2011 (149 days) and period 2 from April 2011 to September 2011 (174 days). For both storage periods the pit was progressively filled with slurry from

different fattening pens (295 and 256 m^3 for periods 1 and 2, respectively). Two approaches were tested to calculate gaseous emission factors: the measurement of gaseous emissions (approach 1) and the measurement of gas concentration gradients ($\Delta[CH_4\text{-}C]/\Delta[CO_2\text{-}C]$ and ($\Delta[NH_3\text{-}N]/\Delta[CO_2\text{-}C]$) combined with knowledge of N and C mass balances (approach 2) (Robin et al., 2010).

To sample the air during both storage periods, a dynamically ventilated tunnel (40 m^3/h air flow rate) covering 0.3 m^2 of the slurry surface was used. This system was tested in a previous study under experimental conditions (in a 13-m^3 pit) (Hassouna et al., 2010). Gaseous concentrations (NH_3, N_2O, CO_2, CH_4 and H_2O) were measured over separate time periods with a photoacoustic infrared analyzer (INNOVA 1412) coupled with a sampler dosimeter (INNOVA 1303) at the tunnel's entrance and exit air flows. During both storage periods air temperature and relative humidity inside and outside the tunnel were continuously monitored, as were wind velocity on the uncovered slurry surface and rainfall. Hourly gas emissions (mg gas h^{-1}) were calculated (approach 1) with differences in gas concentrations (entrance and exit of the tunnel) multiplied by the tunnel's air flow rate and outlet gas density. Gas concentration was linearly interpolated between each measuring period. An estimation based on the slurry pit area and covered area was performed to extrapolate gaseous emissions measured in the tunnel to the entire slurry tank. Finally, because of ammonia emissions' high dependency on wind speed, demonstrated by Sommer et al. (1993) and Balsari et al. (2007), measured ammonia emissions were corrected by considering daily differences between wind speed measurements on the surface slurry covered by the tunnel and the uncovered surface.

Slurry mass balances were conducted to apply approach 2 and to validate gaseous emissions estimated with approach 1. At the beginning and end of storage periods and each time the storage pit was filled, slurry volume was measured, weighed, and its composition analyzed (density, dry matter, pH, total C, Kjeldahl N (TKN), P and K contents). Different methods were used to sample the slurry. Information was collected during pig fattening periods to model P, K, N and C slurry content at the end of the fattening period (BRS, Corpen, 2006). The assumption was made that the model gave reference values for total P and K quantities within the pit (method 0). Sludge remaining in the pit at the beginning of storage and added slurry were analyzed to determine initial amounts of N, C, P and K (method 1: M1). At the end of storage, five methods appropriate for application to commercial livestock production were used in order to identify the one with the highest accuracy. Method 2 (M2) used core drilling to extract a complete column of non-mixed slurry, and method 3 (M3) used the same with mixed slurry. Method 4 (M4) sampled the supernatant layer of mixed slurry. Method 5 (M5) combined individual slurry samples from each batch plus the final sludge. The calculated deficits of H_2O, N and C slurry mass balances should correspond to total emission losses.

2. RESULTS AND DISCUSSION: Outdoor temperature during storage periods varied from -6-23°C (average 7°C) for period 1 and 3-35°C (average 16°C) for period 2. For periods 1 and 2, respectively, average wind velocity on the slurry surface was 0.53 and 0.42 m/s and inside the tunnel was 0.4 and 0.6 m/s. Table 1 presents the initial and final amounts of slurry mass balance for H_2O, P_2O_5, K_2O, C and N for both periods with the different methods of slurry sampling. For final amounts, the method having the amount of P closest to the reference (M1) was M2 for period 1 and M3 for period 2. Use of these methods estimated total C losses for cold and warm periods as 21% and 49% of initial C amount, respectively. For N losses it was 9% and 15% of initial N amount, respectively. With other sampling methods, C losses varied from 10-

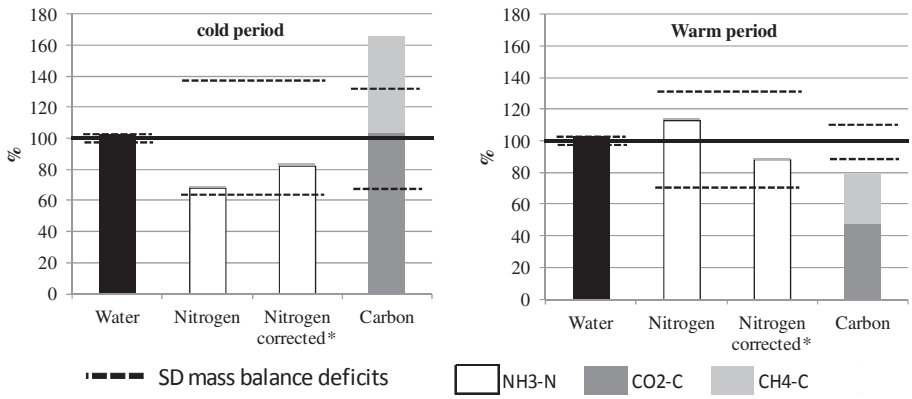
21% for the cold period and 44-59% for the warm period, and N losses varied from 3-9% for the cold period and 15-29% for the warm period.

Table 1. Initial and final amounts of C, TKN, P_2O_5 and K_2O of slurry mass balances.

	Initial amount (kg)	Final amount (kg)						
	M1 corrected*	M2	M3	M4	M5	Mean	SD	CV
	Period 1							
Water	287599	280225	279544	279836	279304	279791	319	0.1
C	4965	3901	4123	3913	4445	4096	254	6.2
TKN	877	798	798	817	853	816	26	3.2
P_2O_5	600	593	703	672	737	676	61	9.1
K_2O	852	825	882	878	862	862	26	3.0
	Period 2							
Water	244837	203427	202234	201953	201819	202358	733	0.4
C	4866	2010	2463	2201	2749	2356	321	13.6
TKN	760	567	644	543	637	598	51	8.5
P_2O_5	670	384	683	482	485	509	125	24.7
K_2O	736	750	783	758	773	766	15	1.9

* M1 underestimated the initial amount of P and K compared to the reference M0. It was corrected considering the sedimentable fraction of each element (100% for P and C, 45% for N and 0% for K)

Total gaseous emission measurements (approach 1) for periods 1 and 2, respectively, were 53 and 137 kg NH_3-N (6 and 18% of initial N amount), 0.5 and 1 kg N_2O-N, 823 and 1198 kg CH_4-C (17 and 25% of initial C amount), and 497 and 801 kg CO_2-C (10 and 16% of C initial amount). Figure 1 compares these measurements to the average deficits of mass balances. Water losses were accurately measured with the tunnel, and mass balances indicated similar losses between sampling methods. Estimated NH_3 emissions, which represent total N losses, were within the range of slurry mass balances. For C emissions, gaseous emissions were respectively higher and lower than the result of the mass balances for periods 1 and 2. These results could be due to a problem with analysis of P and C in sludge between periods 1 and 2. The use of mass balances to deduce NH_3 gaseous emissions (approach 2) estimated between 22-47 kg and 248-335 kg of NH_3-N for periods 1 and 2 (3-5% and 33-44% of initial N amount) respectively. This varies greatly from the known reference (CORPEN, 2003).



*daily ammonia emissions corrected with the air speed on the slurry surface

Figure 1. Total measured gaseous emissions compared to the mean losses of mass balances.

CONCLUSION: The use of mass balances to deduce gaseous emissions from pig slurry storage is not accurate enough for application to commercial farms. The slurry sampling methods provided vastly different results with a different relative importance between period 1 and period 2. Gaseous emissions measured with the tunnel provided correct results, which were attested by the good recovery of water losses. This method could be used for punctual measurements on commercial farms. Data analysis should be completed to identify how to use intermittent measurements to assess emission factors over the entire storage period.

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GASEOUS EMISSIONS DURING STORAGE OF SOLID PIG MANURE: LESSONS FOR FARM MEASUREMENTS

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ABSTRACT: To improve the accuracy of national inventories in France, it is necessary to obtain national references on gaseous emissions from commercial pig farms. The current emission factors used in France are governed by foreign data. Most pig farms are systems with slatted floors. However, systems with solid manure should be considered since they are better accepted by consumers and can represent a model for the future. Gaseous emissions from four solid pig manure storages were measured in 2004, 2006, 2010 and 2011. The heaps (5-10 tonnes) were stored outside during different periods of the year (both cold and warm). A dynamic greenhouse was used to cover the total stored manure and to continuously measure ammonia, nitrous oxide, methane and carbon dioxide emissions. The objectives were to calibrate measurements of gaseous emissions and to ascertain the emissions' dynamics. Gas concentrations were measured by photoacoustic infrared absorption spectrometry using a gas analyzer coupled with a sampler dosimeter. Weather conditions were monitored during storage. Manure heaps' volume and composition were also measured for nitrogen, carbon, phosphorus and potassium mass balance calculations. The results can be used to assess emission factors, and optimal measuring periods can be identified to offer intermittent measurements on pig farms.

Keywords: ammonia, nitrous oxide, methane, gaseous emissions, dynamic greenhouse, methodology, solid manure storage

INTRODUCTION: French pig systems must cope with many pressures (regulations, social expectations, etc.) which may signal the need for change. Because of consumer concerns about animal welfare and environmental considerations, straw-based systems could develop further. Studies show that natural behavior of animals, such as pigs, can be respected with this kind of manure management (Lyons et al., 1995; Tuyttens, 2005). Nevertheless, in France only 10% of pig-production facilities have solid manure management. Straw-based systems are known to have different gaseous emissions compared to slurry systems, but great variability exists in famer practices and litter management. However, data on gaseous emissions from solid manure during storage remains lacking. The objective of this study was to analyze gaseous emissions of solid manure storage to identify ways to assess emission factors on commercial farms.

1. MATERIAL AND METHODS: The study was conducted at IFIP's experimental farm in Romillé (Brittany, France). Four solid pig manure storage periods were followed (2004 and 2011 during cold periods and 2006 and 2010 during warm periods). Manure was stored in heaps to represent commercial practices. For the 4 storage periods the heaps were filled once with solid manure from the pig-fattening period (with the use of straw). To perform manure mass balances, at the beginning and end of storage periods the manure was weighed, and its composition analyzed with standard methods (density, dry matter, total carbon, Kjeldahl nitrogen, and phosphorous contents). To measure gaseous emissions, the heaps were fully covered

by a dynamic greenhouse. Gaseous concentrations (NH_3, N_2O, CO_2, CH_4 and H_2O) were measured continuously with a photoacoustic infrared analyzer (INNOVA 1412) coupled with a sampler dosimeter (INNOVA 1303) at the entrance and exit air flow of the greenhouse (Hassouna et al., 2008). Heated Teflon tubes (25 m long) were used to transport air samples from the sampling location to the analyzer. During storage periods, temperature and relative humidity of outdoor air and inside the greenhouse were continuously monitored. The following expression (Equation 1) was used to calculate hourly emissions of each gas in the manure heaps.

$$Q_{gas} = Q_{air} \times \rho_i \times \left(C^m_{gas,i} - C^m_{gas,o}\right) \qquad \text{Eq. 1}$$

where Q_{gas} is the gas emission (in mg gas h^{-1}) from the manure heap, Q_{air} is the greenhouse air flow rate ($m^3\ h^{-1}$), ρ_i is the outlet gas density (kg dry air m^{-3} humid air), $C^m_{gas,i}$ and $C^m_{gas,o}$ are gas concentrations from the exit and entrance of the greenhouse (mg kg^{-1} dry air).

The emissions' kinetics were analyzed and several days of intermittent measurements were chosen to test simplified methods. Total emissions for each period were assessed with intermittent measurements which were respectively: the mean of hourly emissions (continuous measurements) of each punctual day (test 1), the min (test 2) and the max (test 3). Between each day of intermittent measurements, the emissions were linearly interpolated.

Table 1. Initial manure composition and mass balance deficits.

Year	2004	2006	2010	2011
Initial weight (kg)	5640	8140	7300	9920
Storage time (d)	90	28	76	91
Composition :				
In %: DM	36.1	39.5	30.5	29.6
In g/kg: NTK	12.0	12.6	9.3	8.9
C	-	155.6	118.0	110.5
P_2O_5	15.0	10.8	8.0	5.4
Mass balance deficit in kg *(% of the initial amount)* :				
H_2O	2042 *(57%)*	3241 *(52%)*	2360 *(47%)*	2263 *(32%)*
C		340 *(30%)*	256 *(30%)*	266 *(24%)*
N	19 *(28%)*	19 *(23%)*	10 *(15%)*	37 *(42%)*
DM	446 *(22%)*	470 *(19%)*	550 *(24%)*	857 *(29%)*
P_2O_5	7 *(12%)*	0 *(-1%)*	3 *(6%)*	-2 *(-3%)*

2. RESULTS AND DISCUSSION: The external temperature varied from -3.8-23.5°C (average 8°C), 4.2-33°C (average 15.4°C), 5.9-31.4°C (average 17.6°C) and -6-15°C (average 5°C) for 2004, 2006, 2010 and 2011, respectively. Recovery rates for phosphorous were acceptable in the four experiments (Table 1). In 2004 and 2006, manure initial dry matter contents were higher than those in 2010 and 2011. In 2004, 2006 and 2011, measured N emissions were lower than N losses estimated with mass balances (Table 2), but the differences could be attributed to N_2 losses that could not be measured. In 2006, carbon losses were estimated with mass balances, and good agreement with measured C emissions was found. In 2010 and 2011, measured C and H_2O gaseous emissions were higher than losses estimated with mass balances. These overestimations could be attributed to incorrect estimation of air density.

Table 2. Total gaseous emissions measured and recovery rates compared to total losses estimated with mass balances calculation.

Year		2004		2006		2010		2011	
Time storage (d)		90		28		76		91	
Total emissions in kg / initial t stored *(% recovery rate)*									
H_2O		388.0	*107*	*442.8*	*111*	*556.3*	*172*	*409.6*	*179*
N:	NH_3-N	0.89	*38*	*1.81*	*86*	*1.52*	*124*	*1.30*	*45*
	N_2O-N	0.390		*0.209*		*0.178*		*0.393*	
C:	CO_2-C	36.0		*42.9*	*105*	*43.0*	*125*	*44.3*	*169*
	CH_4-C	1.52		1.08		0.85		0.89	

Concerning kinetics (Figure 1), similar shapes of emissions for NH_3, CO_2 and N_2O were observed between the four storage periods, in agreement with kinetics from the literature (Paillat et al, 2005). Emissions peaked during the three first days of storage, with a lower amplitude of emissions for cold periods than warm periods. During the first 2 weeks of storage, 90% of NH_3 emissions and 60% of CO_2 emissions occurred. Most N emissions were in the form of NH_3, and most C emissions were in the form of CO_2. Six days of punctual measurements were used to test the simplified method. Three punctual measurements were performed on days 2, 3 and 4 to identify peak emissions (main emissions). Intermittent measurements on days 10, 27 and 50 were included to assess the decrease. The estimated emissions of NH_3 and CO_2 with test 1 had an error lower than 24% compared to continuous measurements (Table 3). For estimated N_2O emissions, the error was lower than 15% for 2006, 2010 and 2011. Results with test 2 and 3 showed the variability in hourly emissions within one day.

Table 3. Estimated gaseous emissions compared to continuous measurements (in %).

	2004			2006			2010			2011		
	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
NH_3-N	115	88	155	105	62	163	124	79	153	118	86	150
N_2O-N	147	84	225	110	79	154	115	92	138	97	85	108
CO_2-C	120	75	174	96	74	140	109	96	122	94	80	108
CH_4-C				58	16	224	134	81	213	45	35	57

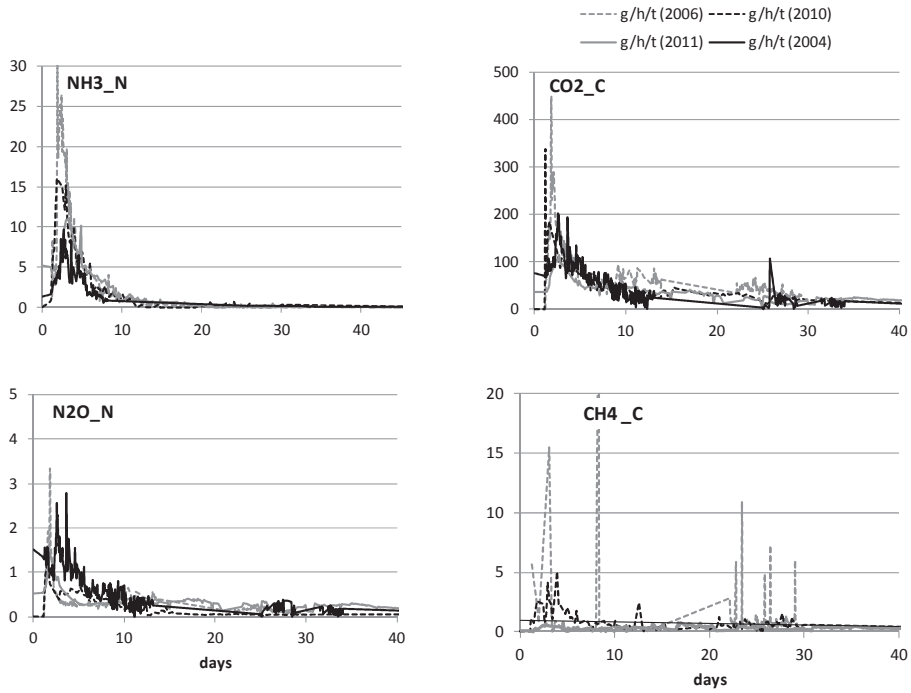

Figure 1. Kinetics of gaseous emissions during 40 days of storage.

CONCLUSION: Similarities between kinetics indicated the ability to identify periods of intermittent measurement that can be used to estimate emission factors on commercial farms. Six days of measurements provided accurate estimation of NH_3, N_2O and CO_2 emissions. The method did not work for CH_4 emissions because no typical kinetic was identified. The intermittent method (Test 1) should be performed by specifying the number and duration of intermittent measurements (to assess average daily emissions) and how to perform them, since the use of manure-storage greenhouses is not practical on commercial farms.

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AIRTIGHTNESS OF COVERED SLURRY STORAGE TANKS DETERMINED WITH THE TRACER GAS TECHNIQUE

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ABSTRACT: The airtightness of three different types of coverings for slurry storage tanks was studied: wooden roof, plastic tent and concrete roof.
The air exchange rates were determined by measuring the decay in concentrations of injected tracer gas sulphur hexafluoride (SF_6) from five different locations in the air space inside the tanks with an infrared spectrophotometer.
The tracer gas SF_6 has a much higher density than normal air. It was not possible to observe any form of layering/accumulation of the gas in any specific areas of the tanks. Different measuring locations showed small differences in the decay process, both with and without mixing the air volume above the slurry. Therefore, the high density of the gas is not a limiting factor for its use in this type of study.
Measured ranges in ventilation rates in relation to the bottom areas of the tanks were 0.60 to 1.12 m^3/m^2 for the wooden roof, 0.30 to 0.36 m^3/m^2 for the plastic tent and 0.53 to 1.61 m^3/m^2 for the concrete roof.
Measurements indicated that wind may have a considerable effect on air leakages. Therefore, it is proposed that measurements of airtightness are made under wind-free conditions.
Measurements also indicated that the areas of openings influence air exchange in the air volume inside the tanks.
Since sulphur hexafluoride is a potent greenhouse gas, other tracer gases must be used in the future. It is suggested that the use of nitrous oxide (N_2O) should be investigated**.**

Keywords: manure, slurry, storage, airtightness

INTRODUCTION: The objective of this investigation was to study whether it is possible to determine air leakage from covered slurry storage tanks using the tracer gas technique by injection of sulphur hexafluoride (SF_6) and measurements of the decay in gas concentrations with an infrared spectrophotometer in the air space above the slurry.

The tracer gas technique is an established method for determining air ventilation rates (Niemala et al, 1984; Roulet, 2005; Moore, 2004) and air leakages (Niemala et al., 1984).

Sulphur hexafluoride has the advantage of being detectable at low concentrations that are far below the hygienic threshold limit value for the gas. It is not present in a normal atmosphere and is chemically stable. A disadvantage is the high density of the gas, which is 5 times heavier than normal air.

According to the Intergovernmental Panel on Climate Change, SF_6 is the most potent greenhouse gas with a global warming potential of 22,800 times that of CO_2. Therefore, other tracer gases must be used in the future.

1. MATERIALS AND METHODS: The leakage of air (q) from a slurry storage tank can be determined by measuring the reduction in concentration over time of a tracer gas that is injected into the air space above the slurry.

By measuring the concentration of the tracer gas on different occasions, the air exchange rate can be calculated from:

$$q = -\frac{V}{t} \cdot \ln\left(\frac{C(t)}{C(0)}\right)$$

where

q = air exchange rate, m^3/h

V = air volume in the tank, m^3

t = time, h

C(t) = tracer gas concentration as function of time, ppm

C(0) = initial tracer gas concentration, ppm

1.1. Studies of coverings: Three different types of coverings were studied: wooden roof, plastic tent and concrete roof.

The air exchanges were related to the bottom areas of the tanks.

2. RESULTS AND DISCUSSION: he studies demonstrated that the tracer gas technique can be a reliable method for determining air leakage from covered slurry storage tanks. The tracer gas used in these studies was sulphur hexafluoride, which has a much higher density than normal air.

It was not possible to observe any form of layering/accumulation of the gas in any specific areas of the tanks (Figures 1 and 2). Different measuring locations showed small differences in the decay process, both with and without mixing the air volume above the slurry (compare Figures 1 and 2). Therefore, the high density of the gas is not a limiting factor for its use in this type of study. Air exchanges at different locations in the air space in the tank with a wooden roof showed small variations within individual treatments.

The measurements clearly showed that wind speeds affected air exchanges throughout the tank. Therefore, external climatic conditions should be standardised when measurements occur. It is proposed that measurements of airtightness are performed under wind-free conditions.

Measurements also indicated that the areas of openings in the storage tanks influence air exchanges in air volume inside the tanks.

The mean values of air exchanges for the tanks varied between 0.33 and 0.86 $m^3/m^2.h$. The plastic tent had the lowest air exchange in relation to the bottom area.

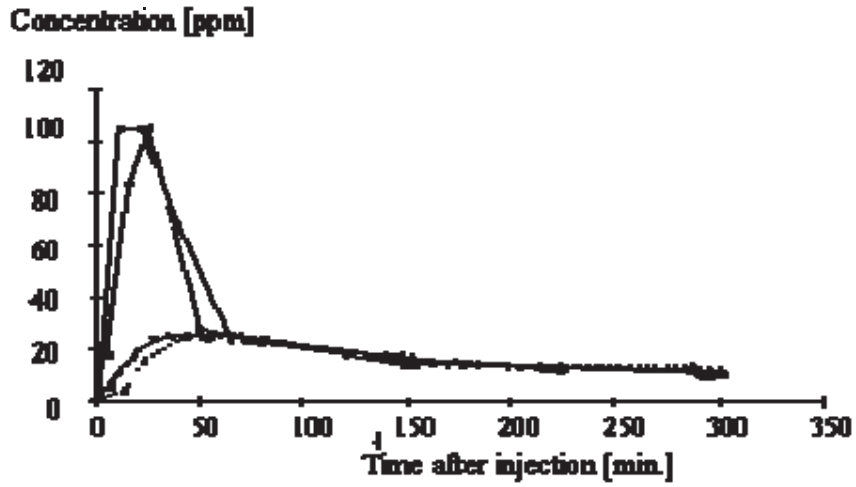

Figure 1. Decay of tracer gas concentrations at different measuring locations when air mixing occurred in a storage tank with wooden roof.

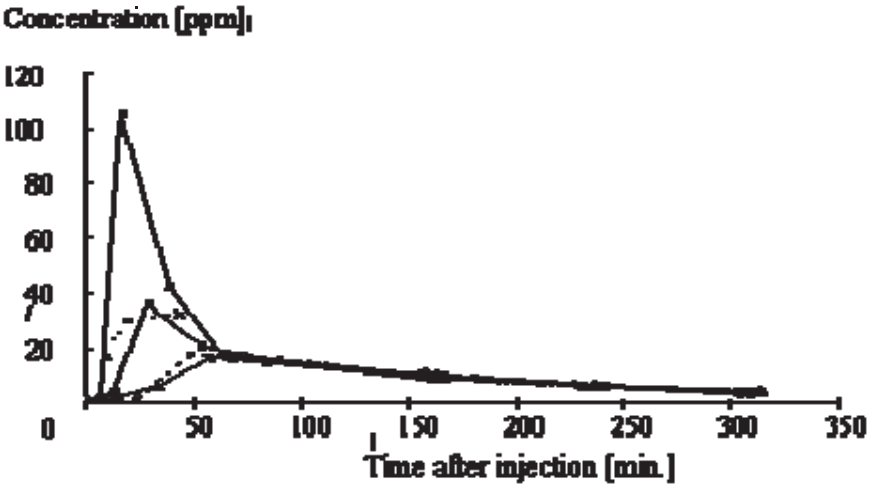

Figure 2. Decay of tracer gas concentrations at different measuring locations when no air mixing occurred in a storage tank with wooden roof.

CONCLUSIONS: The studies demonstrated that the tracer gas technique can be a reliable method of determining air leakages from covered slurry storage tanks. The tracer gas used was sulphur hexafluoride, which has a much higher density than normal air. It was not possible to observe any form of layering/accumulation of the gas in any specific areas of the tanks. Different measuring locations showed small differences in the decay process, both with and without mixing the air volume above the slurry. Therefore, the high density of the gas is not a limiting factor for its use in this type of study. Air exchanges at different locations in the air space in the tank with a wooden roof showed small variations within individual treatments.

Measurements indicated that wind may have a considerable effect on the air leakages. It is proposed that measurements of airtightness are performed under wind-free conditions.

Measurements also indicated that the areas of openings influence the air exchanges inside the tanks.

A plastic tent had the lowest air exchange in relation to the bottom area.

Since sulphur hexafluoride is a potent greenhouse gas, other tracer gases must be used in the future. It is suggested that the use of nitrous oxide (N_2O) should be investigated.

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METHANE PRODUCTION FROM DEXTER CATTLE FED THREE DIFFERENT DIETS AND MEASURED BY THE CO_2 METHOD

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ABSTRACT: The methane production of three Dexter heifers fed three different diets in a Latin square experiment was established using the CO_2-method. The average weight of the heifers was 226 (208-241) kg and the diets consisted on DM basis of 49% grass-clover silage, 14% soybean meal and 35% of one of three supplements: Wheat (W), Molasses (M), and Molasses + sodium bicarbonate (Mbic). The diets were fed as a total mixed ration. It is concluded that the differences in CH_4 production among the tested diets was of the same magnitude as the difference among heifers. Establishing precise CH_4 production from different diets requires measurements of many animals.

Keywords: methane, cattle, Dexter cattle, CO_2-method

INTRODUCTION: Methane (CH_4) is an undesired byproduct of rumen fermentation. The CH_4 emissions from ruminants is both causing a loss of energy potentially used by the animals and is a concern as greenhouse gases lead to additional global warming. The amount of CH_4 released from individual ruminants is mainly determined by the level of feed intake and dietary composition (McAllister et al., 1996), but may also be determined by the species of ruminant and maybe even hereditary (Lassen et al., 2011). The fermentation pattern and volatile fatty acid (VFA) production determine hydrogen (H^+) production. The H^+ is then removed by microbial production of CH_4. Several studies indicate an influence of both carbohydrate source as well as rumen pH on the rumen fermentation pattern and thereby the H+ production. As the interest for ruminant CH_4 production has increased and other pathways are known to exist for removal of H^+ from the rumen without CH_4 production, the need to directly measure this gas is necessary. Respiration chambers have traditionally been used to quantify the CH_4 production from animals. However, Bhatta et al., (2007) describes a disadvantage of this method in that it is difficult to ensure correct measurements when the animals are not in their natural environment. Recently, an inexpensive, quick and simple method, referred to as the CO_2-method, was developed and is believed to surpass the limitations of the respiration chamber (Madsen et al., 2010).

The present study was designed to estimate the effect of different sources of carbohydrate supplementation on CH_4 emission measured by the CO_2-method.

1. MATERIAL AND METHODS:

1.1. Experimental design, animals and diets: The experiment was a (3X3) Latin square design where three Dexter heifers were allocated to balance cages (Figure 1). The average body weight of the animals was 226 kg (range of 208-241 kg). Three different total mixed rations were fed to the animals twice daily. The rations consisted of, on DM basis, 49% grass-clover silage, 14% soybean meal and 35% of one of three supplements: Wheat (W), Molasses (M), and Molasses + sodium bicarbonate (Mbic). The chemical composition is shown in Hellwing et al. (2012).

1.2. Methane and carbon dioxide measurement: Breath from the animals was continuously sampled and analyzed every 20 seconds to determine the concentrations of CH_4 and CO_2 by a portable continuous gas analyzer GASMET DX-4030 (Gasmet Technologies Oy, Helsinki, Finland) based on Fourier Transformed Infrared (FTIR) detection. The analyzer filter was fitted in a balance cage close to the nose of the animals (Figure 1) to obtain a relatively concentrated breath sample. The record of the concentrations of breath samples was stored in a portable computer connected to the Gasmet (Figure 2). All gas volumes are reported at 0^oC and 100 kPa. Measurements were performed for 24 hours, after which the heifers were moved from the metabolic cage to traditional respiration chambers for CO_2 measurements. To obtain the background concentration of the air, the Gasmet was moved from directly above the water cup in the balance cage to a position inside the room, 2-5 meters from the cages with measurements occurring for 10 minutes during each experimental period.

Figure 1. Heifer in balance cage. (Tube for collection seen in the left edge of picture).

Figure 2. The portable Gasmet FTIR analyser.

1.3. Calculation and statistical analysis: The background concentration of CO_2 and CH_4 was subtracted from the exhaled air of the heifers to obtain the breath concentration. After correction, all values below 800 ppm of corrected CO_2 were deleted. The average CH_4/CO_2 ratio was calculated and this ratio was multiplied with calculated animal CO_2 production, using the formulas by CIGR (2002) and Pedersen et al., (2008) according to Madsen et al., (2010). The data was analyzed using a mixed linear model (proc mixed) using the statistical program SAS (version 9.3, SAS Institute Inc., Cary, NC).

2. RESULTS AND DISCUSSION: The average measured molar ratio of CH_4 to CO_2 in the heifers' breath was 0.077, 0.083 and 0.087 for the diets W, M and Mbic. The average CH_4 production (±SD) was 26.4±1.7, 28.5±4.1 and 29.8±0.7 L/kg DM intake for diet W, M and Mbic. The three heifers had average CH_4 production of 26.2±2.7, 28.6±1.7 and 29.9±2.9 L/kg DM intake. The calculated CO_2 production was 1,761 L/day by using the average daily weight gain of 500 g based on the actual weights of the heifers. The average CO_2 production measured in the respiration chambers was 1,785 L/day. On average, there was a positive relation between the calculated and measured CO_2 production and; therefore, also the calculated CH_4 production using the two different methods for establishing the amount of CO_2. The linear relation between live weight and the animals CO_2 production differs between the methods. In a conventional respiration chamber experiment, Thorbek (1980)

described the relationship between the weight of bull calves and CO_2 production from a conventional respiration chamber experiment, and this relation agrees with the calculated CO_2 production based on the CO_2 method described above (Figure 3.). The CH_4 production for the three heifers is shown in Figure 4 and for the three diets in Figures 5 and 6, using the two different methods for establishing CO_2 production. The estimated average CH_4 production was 146 L/heifer/day. All heifers produce CH_4 (L/kg DMI/day) with a similar trend when fed the experimental diets. However, the response of diet M was different for a single heifer, but similar for the other two (Figure 4). The measured CH_4 (L/kg DMI) production for diet Mbic was similar in all heifers, whereas diet W and M produced slightly more variable amounts (Figure 5 and 6). The same trend was observed both when the amount of CH_4 (L/kg DMI) was calculated based on CO_2 obtained from a formula considering average body weight and weight gain 500 (g/day), and when CO_2 was measured in the respiration chambers.

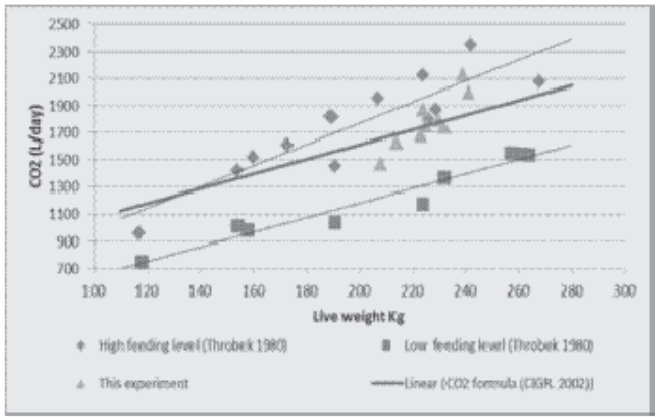

Figure 3. Relation between live weight and CO_2 production.

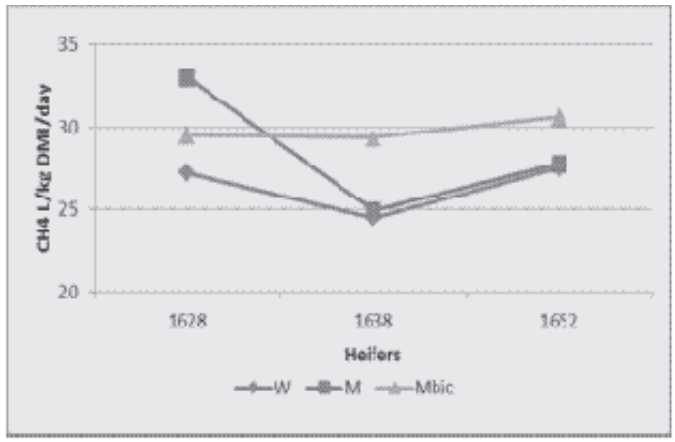

Figure 4. CH_4 production by the three heifers fed the three diets.

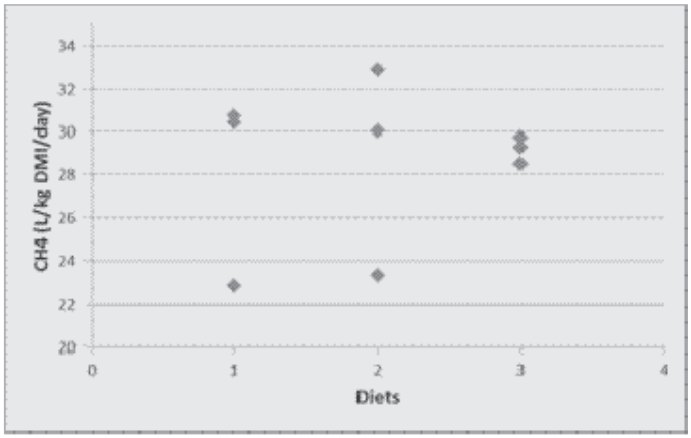

Figure 5. CH_4 production using measured CO_2 production.

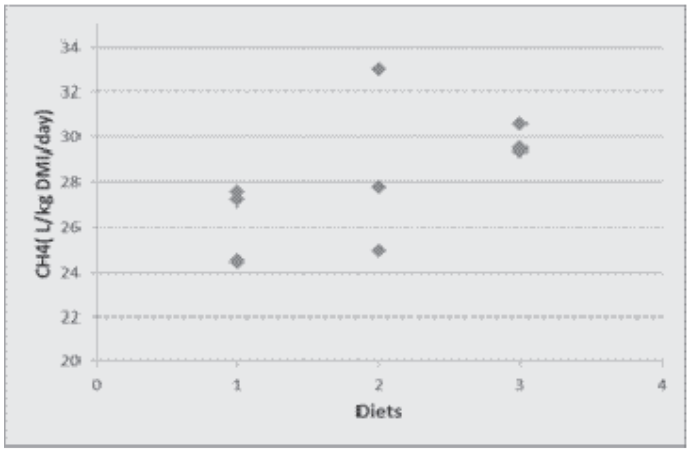

Figure 6. CH_4 production using calculated CO_2 production.

No statistical differences were found in CH_4 production among diets due to the low number of animals and the relatively large difference among animals. Therefore, more precise CH_4 production is measured with more animals. The CO_2-method was specifically developed to quickly and inexpensively measure many animals, particularly in a practical commercial dairy herd and other typical animal housing where the animals are in their natural environment.

CONCLUSION: It is concluded that the differences in CH_4 production among the tested diets was of the same magnitude as the difference among heifers. Establishing precise CH_4 production from different diets requires measurements of a large number of animals.

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MEASUREMENT OF ODORANTS IN LIVESTOCK BUILDINGS: SIFT-MS AND TD-GC-MS

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ABSTRACT: Air samples from animal farming are analysed in parallel using traditional TD-GC-MS (thermal desorption gas chromatography mass spectrometry) and SIFT-MS (selected ion flow tube mass spectrometry). In samples from 4 different livestock buildings, 23 odorous compounds are detected and quantified based on TD-GC-MS, including organic acids, sulphur compounds and phenols. Significant concentration differences are found between pig stables and poultry houses. SIFT-MS spectra show similar differences in product ion intensities, suggesting SIFT-MS as a promising fast technique for evaluation of odorous emissions from livestock buildings.

Keywords: swine, poultry, VOCs, odorants, SIFT-MS, TD-GC-MS

INTRODUCTION: Odour nuisance related to intensive livestock breeding is an emerging concern, especially in areas with a high population density (Van Langenhove and De Bruyn, 2001). Volatile organic compounds (VOC) are generated by microbial conversions in the gastrointestinal tract of farm animals, in excretions and in the litter (Le et al., 2005). Some of these compounds, such as phenols, indoles, organic acids, sulphur compounds and amines, have an offensive odour and low odour thresholds, and are suggested as the key VOC emitted from swine houses (Yao et al., 2011), poultry excretions (Cai et al., 2007) and cattle feedlots (Trabue et al., 2011).

For treatment and prevention of odorous emissions, identification and quantification of the various offensive odorants is necessary (Lehtinen and Veijanen, 2011). Until presently, no general method existed to provide an evaluation of odorant production, although a great number of indirect measurement methods have been developed (Hansen et al., 2011). The main limitation of GC-MS is the temporal resolution, which emphasizes the need for a more convenient and faster technique (Blake et al., 2009). In recent research (Liu et al., 2011), proton transfer reaction mass spectrometry (PTR-MS) was applied in a piggery, achieving real-time measurement of the odorous emissions, including gases such as H_2S. Likewise, Feilberg et al. (2010) employed membrane inlet mass spectrometry (MIMS) to develop an online evaluation of a livestock air biofilter. Begnaud et al. (2004) used solid phase micro-extraction mass spectrometry (SPME-MS) to yield a spectral signature of different animal sheds. Similarly, selected ion flow tube mass spectrometry (SIFT-MS) has been applied on livestock samples (Smith et al., 2000), and is used in this study as a fast analysis method, combined with GC-MS to validate the identification of compounds.

1. MATERIAL AND METHODS:

1.1. Field sampling: Samples were taken at a test facility of the ILVO (Institute for agriculture and fisheries research) in Merelbeke. Animal houses with different species are studied, including laying hens, broiler chickens, fattening pigs and piglets. In each livestock building, at 1.5 m height above the animals, 5 air samples were collected within 30 min in 2 L Nalophane® bags. The average temperature in the buildings was 21 °C.

1.2. Laboratory analysis:

1.2.1. TD-GC-MS: Sampling tubes (Markes, Tenax TA/Carbotrap) were loaded from the sampling bags within 6 hours after filling. Before sampling, tubes were conditioned for 1 hour at 300 °C and loaded with deuterated toluene as an internal standard. Each tube was loaded with 300 mL sample using a Flec air pump at 100 mL min^{-1}. TD-GC-MS analysis began with tube desorption in a Unity Series 2 Thermal Desorption system (Markes, Llantrisant, UK) at 260 °C for 10 min with a He flow of 20 mL min^{-1}. After desorption, analytes were refocused on a Tenax TA coldtrap, which was flash-heated from −10 °C to 280°C. Separation was accomplished on a FactorFour VF-1ms column (Varian, Sint–Katelijne–Waver, Belgium; 100 % dimethylpolysiloxane, 30 m x 0.25 mm x 1 μm) with He as a carrier gas and a constant column head pressure of 70 kPa was applied. The GC (Focus GC, Interscience) oven temperature was initially set at 35°C for 3 min, and increased from 35°C to 150°C at 8 °C min-1 and from 150 to 240°C at 12 °C min-1, which was maintained for 10 min. A DSQ II Single Quadrupole MS (Thermo Scientific, Austin, TX, USA) hyphenated to the GC was operated at full-scan mode (140 ms per scan). Data were processed in XCalibur software based on retention time, mass spectrum and selected ions.

External standard calibration for TD-GC-MS was performed by means of a standard solution containing the target compounds in methanol. Selection of these compounds was based on different criteria, including reported odour detection thresholds (ODT) and earlier demonstration that a compound contributes to livestock odour.

1.2.1. SIFT-MS: A Voice 200® (SYFT Technologies Ltd) was used with the downstream quadrupole mass spectrometer in the m/z range 15 to 250. To prevent condensation of water vapour, the sample inlet lines were heated to ~ 373 K. He carrier gas pressure was 20 Pa at room temperature (296–300 K).

2. RESULTS AND DISCUSSION:

2.1. TD-GC-MS: The most abundant compound in all samples was ethanoic acid (EA), reaching more than 40 mass percent of the total concentration. Other dominant compounds were propanoic and butanoic acid (respectively PA and BA) for both pig stables, 2-butanone and phenol for the broiler chickens and dimethyl sulfide (DMS) and dimethyl disulfide (DMDS) for the laying hens.

Based on ANOVA statistical tests, several compounds show significant concentration differences (on the 0.05 level) between the livestock buildings. In Figure 1, a selection of compounds is shown where symbols indicate a significantly higher concentration in the sample shown left compared to the top sample. Generally, pig stables show higher concentrations compared to poultry houses.

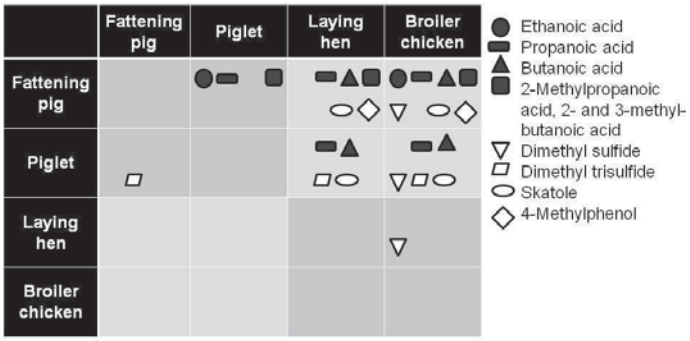

Figure 1. ANOVA results: significant differences between livestock samples.

2.2. SIFT-MS: The SIFT-MS spectra (n=15) show differences between the various animal housing atmospheres. In Figure 2, an example is given of mass spectra in counts per second (CPS) for laying hens and piglets, generated with NO^+ as precursor ion. Most ions were detected in both samples, but have significantly higher intensities in one sample, for example product ions with m/z 71 and 118 of butanoic acid and 104 of propanoic acid. As seen in the TD-GC-MS results, these organic acids were more abundant in the piglet stable compared to the laying hen stable. Not all product ions could be identified and some can be appointed to multiple compounds, but similar patterns were observed for several other odorants and in the mass spectra generated with H_3O^+ and O_2^+.

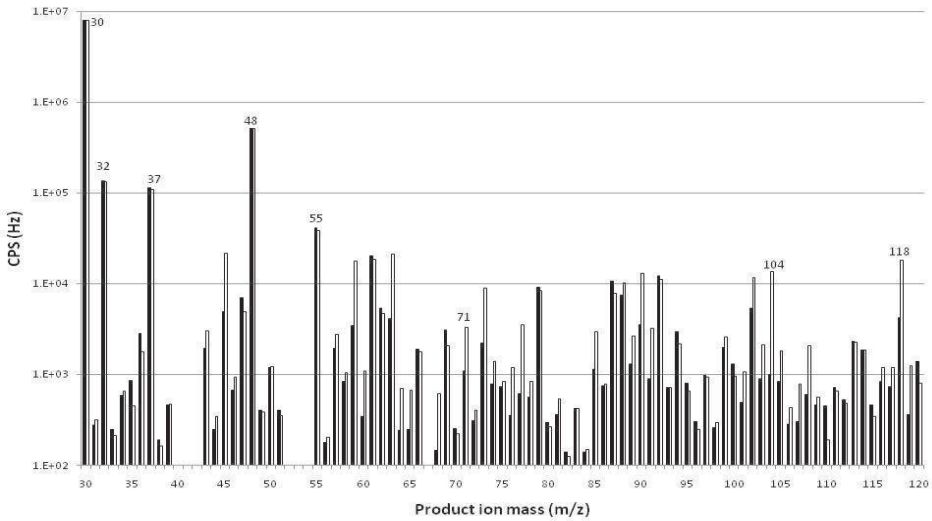

Figure 2. Typical SIFT-MS spectra obtained by the analysis of laying hen (black) and piglet (white) atmospheres. m/z 30, 32, 37, 48 and 55 are precursor ions.

CONCLUSION: In this research the established GC-MS technique was used in parallel with fast and innovative SIFT-MS. Both analysis methods can distinguish between samples from different livestock buildings, which can be useful for appointing the source of odour nuisance. In the GC-MS chromatograms, 23 compounds were identified and quantified, of which the majority showed higher concentrations in pig stables compared to poultry houses. SIFT-MS appears a suitable

method for fast analysis of air samples from animal farming. In further research, a database of parallel measurements will be built, which will improve the knowledge about VOC levels in and emissions from intensive livestock breeding and will facilitate the interpretation of SIFT-MS spectra.

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A NEW METHOD FOR ESTIMATING AMMONIA VOLATILISATION FROM SLURRY IN SMALL FIELDS USING DIFFUSION SAMPLERS

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ABSTRACT: Atmospheric ammonia (NH_3) is a major threat to the environment. It is mainly emitted through agricultural activities, primarily from the animal sector and following organic and mineral fertilization, and consequently affects the economic effectiveness of fertilization. The need remains for a method easy to deploy under real conditions to better characterise the variability of NH_3 emissions. In this study, we assess the capability of an inverse modelling approach to infer NH_3 volatilisation from multiple fields placed side by side, using NH_3 concentration passive sensors that measure for a period ranging from several hours to several weeks. Four calculation strategies were tested: they agreed in providing the largest emissions for surface-applied slurry. The emissions estimated from replicated plots were also found to agree within 21% in the two treated cases.

Keywords: ammonia, volatilisation, inverse modelling, multiple sources and targets, slurry

INTRODUCTION: Tropospheric ammonia is mainly emitted by agriculture and has great environmental impacts (atmospheric pollution, eutrophication, biodiversity) which are increasingly included in European regulations. The increasing price of mineral fertilizers and concerns regarding the nitrogen cascade require improvements in the efficiency of nitrogen fertilization, and especially organic fertilization. Volatilisation following application of manure and slurry is a significant source of ammonia emission in France (CITEPA 2011). Therefore, reducing ammonia losses from this sector is a major objective for applied research. However, characterising these emissions at the field scale often requires heavy experimental designs (Spirig et al., 2010) and simpler methods are challenged (Sintermann et al., 2012). In this study, we extend the inverse modelling approach by Loubet et al. (2010) to estimate NH_3 emissions from multiple fields with multiple concentration sensors. Such methods have been applied for longer range transport (Flesch et al., 2009; Yee and Flesch, 2010), and were shown as highly dependent on the source-sensor geometry (Crenna et al., 2008).

1. MATERIAL AND METHODS: Two experiments were performed in spring 2011, one with pig slurry (Bignan) and the other with cattle slurry (La Jaillière). In each experiment, three treatments were compared: no application, surface application and incorporation into bare soil. Two replicates for each treatment were compared. The six plots were statistically randomised and consisted of rectangular fields of more than 400 m^2. The dimensions of each field ranged from 20 × 20 m to 40 × 20 m. Soil

mineral N content was measured in the 0-0.3 m soil layer allowing indirect estimation of mineral N loss from slurry application using the soil mineral N balance (Cohan et al., 2012). Two diffusion samplers (α-badges, Sutton et al., 2001) were placed in the middle of each field at 0.3 and 1.0 m above the ground and sampled from 2 hours to 20 days. Three masts were placed around the field at 3 m height to catch the background concentration. A meteorological station recorded hourly averages of global radiation, air temperature, relative humidity, wind speed and wind direction.

2.1. Inversion method: The inversion method consisted of three steps: (1) the surface energy balance of the Volt'Air model (Génermont and Cellier, 1997) was used to retrieve the surface layer parameters (friction velocity u_* and Obukhov length L) from hourly meteorological data; (2) the three-dimensional FIDES dispersion model (Loubet et al., 2010) was then used to estimate the hourly transfer coefficient from each plot to each α-badge location (including background masts); (3) the sources from each field were then estimated by optimising (by linear least square) the difference between the modelled and measured concentration using four strategies detailed hereafter. The measured concentrations were first expanded to an hourly time step.

2.2. First inversion strategy: In the first strategy, the sources S_i were estimated as

$$S_i = \frac{C_i(30cm) - C_{bgd}}{h_i^i(30cm)} \quad (1)$$

where C_i(30cm) is the concentration measured at 30 cm height in the middle of the i^{th} field, C_{bgd} is the measured background concentration, and $h_i^i(30cm)$ is the transfer coefficient between the i^{th} field and the concentration sensor at 30 cm height in the same field.

2.3. Second inversion strategy: In the second strategy, the sources S_j were estimated by minimising by linear least square the difference between measured C_i(meas) and modelled C_i(mod) concentrations at all locations, where the modelled concentration was estimated as:

$$C_i(\text{mod}) = h_i^j \times S_j + C_{bgd} \quad (2)$$

where h_i^j is the transfer coefficient from the j^{th} field to the i^{th} sensor, and C_{bgd} was fixed.

2.4. Third and fourth inversion strategies: The third strategy is similar to the second, but in this case C_{bgd} was considered a fitting parameter and was estimated together with the sources S_j. Seven parameters were estimated in the minimising procedure. The fourth strategy was identical to the third, but in this case the sources S_j were considered equal in the two replicates of each treatment. Only four parameters were estimated in the minimising procedure.

2. RESULTS AND DISCUSSION: The four inversion strategies were consistent in estimating that largest NH_3 emissions occurred from the surface application for both cattle and pig slurry. They also systematically estimate that NH_3 emissions were not significantly different from zero in the plot without application and with incorporation. Strategies 3 and 4 generally gave larger background concentrations and lower emissions than strategies 1 and 2 which considered smaller background

concentrations. Strategy 4 led to a reduced confidence interval. On average, the differences between the replicates were smaller than 21% for the surface application plots with high fluxes and larger than 42% for the two other treatments with low fluxes (e.g. Table 1 for cattle slurry).

Table 1. Estimated NH_3 emissions with the four strategies for the cattle slurry trial. The confidence interval is given under brackets. Site La Jaillère. (N applied: Ntot: 114, N-NH_3 39 kg N ha^{-1}).

	Emissions (kg N-NH_3 ha^{-1})				average difference between replicates
	Method 1	Method 2	Method 3	Method 4	
No application	0.7	-0.6 [-9 : 8]	-1.8 [-9 : 5]	-1.2 [-7 : 4]	49% [38% : 69%]
Cattle slurry (surface)	7.4	7.1 [-1 : 16]	5.7 [-1 : 13]	5.9 [0 : 12]	4% [1% : 8%]
Cattle slurry (incorporated)	1.0	0.3 [-8 : 9]	-0.6 [-8 : 7]	-0.6 [-5 : 4]	149% [39% : 252%]
C_{bdg}	5.7	5.7	7.9 [5 : 11]	8.1 [5 : 11]	-

This inversion method is challenging because of the small size of the plots and because all plots are located near each other. Indeed, a strong NH_3 emission in one plot will influence the concentration measured in the other plots. Furthermore, the concentration measurements integrate over several stability conditions, which have different transfer coefficients. In this context, the role of the replicates is essential to validate the estimated flux. The difference between the two replicates was small for the largest emissions (less than 21%), which provides confidence in the ability of this method.

However, NH_3 fluxes are proportional to the concentration difference between the surface and the atmosphere, leading to potentially strong oasis effects in this setup (Loubet et al., 2010). This characteristic was not considered in the inversion approach tested here (sources S_i were considered homogeneous over the surface). Evaluating the influence of these oasis effects would be a relevant issue for further studies.

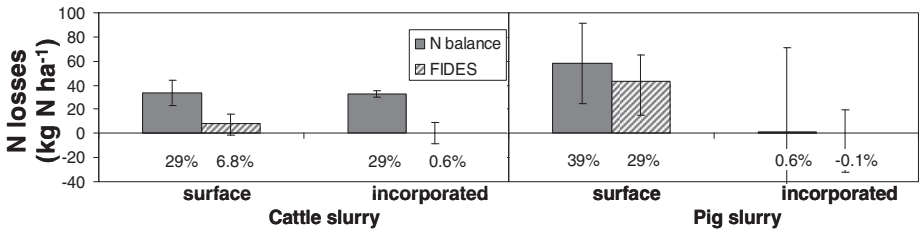

Figure 1. Comparison of nitrogen losses estimated with the nitrogen balance method (N-balance) and the inverse modelling approach (FIDES). The ratio of the losses to the total nitrogen applied is given in percentages.

Regarding the inversion method overall, the cattle slurry surface application was always found as a significant source of NH_3. The pig slurry was found to lead to NH_3 emissions up to 29% of the applied nitrogen, while the cattle slurry led to NH_3 emissions of around 7% of the applied nitrogen. The incorporation was found to be an efficient method to reduce NH_3 emissions, whatever the NH_3 emission magnitude. The inversion method agreed with the N balance method in ranking the emissions but provided lower losses than the N balance in the cattle slurry experiment in particular (La Jaillière).

CONCLUSION: The inversion method was found to provide consistent results with several inversion strategies. The inferred NH_3 emissions were similar between replicated plots giving confidence in this method. The NH_3 emissions were found to be 6.8% and 29% of the applied nitrogen for surface applied cattle and pig slurry and were found to be not significantly different from zero for the incorporated slurry.

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AMINE EMISSIONS FROM AGRICULTURE: NEW FINDINGS REGARDING SOURCE ALLOCATIONS

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ABSTRACT: Recent evidence shows that volatile amines play an important role in the nucleation of particulate matter. Previous measurements in animal housing identified livestock husbandry as an important amine source, dominated by trimethylamine (TMA). Assessments of global sources assumed that agricultural sources for amines are the same as for ammonia, emitted throughout the cascade of animal excretion, storage and application in the field (Schade and Crutzen, 1995) with a TMA: NH_3 ratio between 0.5 and 1%. Kuhn et al., (2011) found a similar ratio in animal housing, but a two orders of magnitude lower ratio in the headspace of slurry tanks and in emissions after slurry application. Laboratory experiments attest that high concentrations of amines (and a respective high TMA:NH_3 ratio) build up during ruminant digestion. Kuhn et al. suggested that exhaled air from ruminants might be an important source for the amines found in animal housing. To test this hypothesis, we performed new measurements in a dairy stable using a combination of fast chemical sensors allowing the measurement of NH_3, TMA, CH_4 and Acetone. As high levels of Acetone or CH_4 are tracers for exhaled air, they are not correlated with elevated TMA:NH_3 ratios nor with elevated TMA concentrations we falsify in this hypothesis.

Keywords: amines, trimethylamine, dairy systems, stable

INTRODUCTION: Trimethylamine (TMA) is an odorous nitrogen-bearing organic compound that represents an important alkaloid constituent in the earth's atmosphere besides ammonia (NH_3). Volatile amines potentially play an important role in the formation of new particulate matter (Angelino et al., 2001; Makela et al., 2001; Kurten et al., 2008, Smith et al., 2010; Bzdek et al., 2010). Previous measurements in animal housing led to the assumption that agricultural sources for amines are dominated by TMA and scales with ammonia emissions (Schade and Crutzen, 1995). Agriculture constitutes the most important global source of NH_3, primarily by way of emissions from cattle manure (Steinfeld et al., 2006). Consequently, agriculture is also a key source for global amine emissions. Micrometeorological flux measurements, as well as dynamic enclosure experiments, suggest that the amine source strength from stored slurry is negligible while animal housing air showed typical elevated TMA:NH_3 ratios (Kuhn et al, 2011). Kuhn et al. hypothesized that the TMA emissions due to the animal's rumination activity and exhalation may be a primary emission pathway, but they did not investigate high TMA:NH_3 ratios directly in the breath of ruminants.

MATERIAL AND METHODS: Measurements were made in July and August 2011 in a dairy stable at the ALP research station in Posieux, Switzerland. Tracing ambient concentrations of amines and organic compounds was done with a PTR-ToF, (Graus et al., 2010), NH_3 with a HT-CIMS (Sintermann et al., 2010) and CH_4 with a Los Gatos, Cavity Ring Down Analyzer. The PTR-ToF and HT-CIMS shared a strongly heated inlet line (150°C) with a high (100 l/min) flow to obtain a measurement time resolution of seconds. This setup allowed to trace breath compounds such as CH_4 and acetone, as well as NH_3 and TMA, with the flexible inlet line that was placed by hand

as close as possible to the mouths of the cows. The high mass resolution of the PTR-TOF was used to separate TMA (60.0808 Th) from acetone containing one ^{13}C atom (60.0525Th).

2. RESULTS AND DISCUSSION: The measurements began on July 28th 2011 and lasted until August 5th 2011. Figure 1 shows TMA and acetone concentrations in a sequence when the inlet line was placed as close as possible to the mouths of the cows. Elevated percentage of breath air is marked with the acetone peaks that serve as a marker for breath air (Mottram, T, 1997). TMA and acetone concentrations are not correlated and especially high acetone concentrations do not show enhanced TMA concentrations.

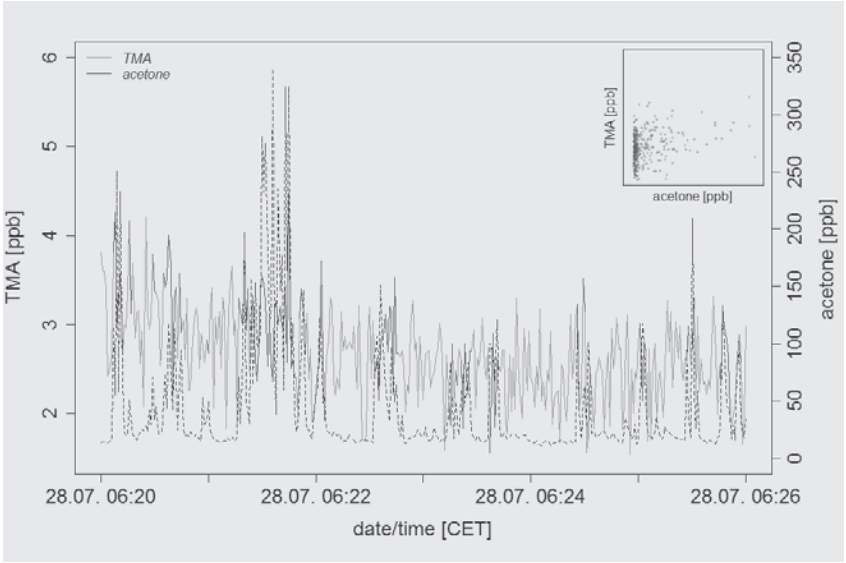

Figure 1. Detailed time series of acetone and TMA concentrations in ppb in the morning of 28th of July. The inlet plot shows the scatterplot of TMA and Acetone concentrations.

Figure 2 shows a 2 days' time series of CH_4 and TMA:NH_3 ratio. The inlet line was placed above the milking parlor waiting room. Cows were always present in the morning between 4:00 and 7:00 and after noon until 16:00. The presence of cows clearly goes along with elevated CH_4 concentrations. Highest values of the ratio TMA:NH_3 lags behind the CH_4 concentrations by approximately 2 hours. This indicates the interaction of urine and dung deposited on the floor as the most important TMA source. Dung contains the enzyme urease that catalyzes the hydrolysis of urea in the urine. This process leads to an elevated pH in the urine/dung mixture on the floor (reference) that enables the volatilization of TMA.

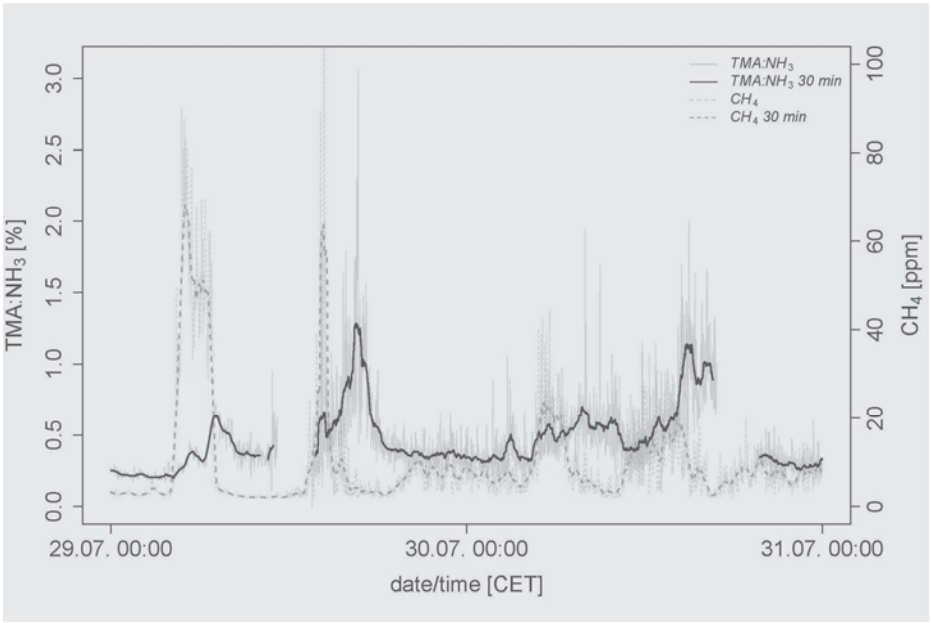

Figure 2. CH_4, and TMA:NH_3 ratio during two days (29th and 30th of July 2011).

CONCLUSIONS: New measurements with a combination of fast and sensitive analyzers to trace volatile organic compounds, NH_3 and TMA revealed that the interaction of urine and dung on the animal housing floor is a strong source of TMA. The hypothesis that exhaled air is a significant source could not be verified.

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MONITORING GAS EMISSIONS IN OPEN-CIRCUIT CHAMBERS WITH A MEASURING DEVICE THAT CAN BE USED FOR MEASURING EMISSIONS FROM MANURE

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ABSTRACT: To study animal emissions and possible shifts from rumen to manure, we built six open-circuit respiration chambers that are flexible and modular. In addition to methane, we also monitor carbon dioxide, nitrous oxide and ammonia in the chambers. For certain trials, measuring these gases in the manure could also be interesting; therefore, we constructed manure trays in the chambers. By fitting the manure trays with wheels, we facilitated quick and easy removal of manure, without opening the doors of the chambers. The collected manure could then be transferred to a barrel for simulating manure pits to study possible shifts in emissions. The equipment is configured to use the same devices for measurements in both the chambers and in manure barrels. The gas analyser is an infrared laser optical-feedback cavity-enhanced absorption spectrometer (OFCEAS). It is interference free and self-calibrating with no instrumental drift. The whole measuring system functions at continuous under-pressure of 110 mbar, created by a 50 µm sonic nozzle at each sampling point. The detection ranges for CH_4, CO_2, N_2O and NH_3 are set between 0-700 ppm, 0-5000 ppm, 0-5 ppm, and 0-70 ppm, respectively. The chambers are continuously monitored for temperature, air flow, water, system pressure and gas concentrations. When values are above or below the set thresholds, the operator is alerted by phone. This system for measuring gas emissions has no interference between the gases and has low maintenance costs.

Keywords: greenhouse gas emissions, open-circuit chamber, manure

INTRODUCTION: Livestock produces emissions which may interact with each other. A measure to reduce emissions of one gas can lead to increased emissions of another gas or the same gas in a later stage. An example is the possible shift of emissions of greenhouse gases of ruminants from the rumen to the manure due to reduced digestibility of the feed. To study animal emissions and possible shifts, the Animal Sciences Unit of the Institute for Agricultural and Fisheries Research built six open-circuit chambers that are flexible and modular.

1. MATERIAL AND METHODS: The six open-circuit chambers were designed not only to enable accurate measurement of methane emissions but also of carbon dioxide, nitrous oxide and ammonia, and to facilitate comfortable collection of faeces and urine. The installation is a combination of three major parts: the actual chambers, the ventilation system and the gas analysis system.

1.1. Chambers: The six chambers, with an internal volume of 12.3 m^3 each, are made of polypropylene (PP) panels mounted on an internal stainless steel frame. Each chamber has large windows and three doors: one lateral door for milking, one entrance door in the back and one front door for feed supply. To reduce the feeling of captivity and improve visual contact between cows, natural lighting in the chambers was maximised by using large windows in each door and in the side panels. The three other openings in the chamber are the air inlet in the front door, the air outlet in the

rear part of the roof and the manure tray situated under the back door. Inside the chamber, the floor is raised by 350 mm to integrate a 1450 long manure tray in the rear part of the chamber (Fig. 1). A custom-made galvanised metal slatted grid is installed above the tray. In front, a PP feed bin is placed with an opening for eating. A drinking bowl, with a non-spill edge and water meter is attached to the side wall. A comfortable three-layered mat, 1830 by 1300 mm, is placed on the floor. Cows are tied with a vertical chain tying system.

1.2. Ventilation: The ventilation system is a temperature controlled mechanical central flow system, where one central exhaust fan induces the airflow through the six chambers. Fresh air enters each chamber via an adjustable opening in the lower panel of the front door. The air outlet is situated in the roof panel at the rear. In this opening a ventilation module with a 350 mm diameter is placed. This module is equipped with an integrated full size free-running impeller that continually measures the airflow and a control damper that regulates the amount of air. The module connects with a 12.6 m long central ventilation duct. Finally, the air is evacuated by the central axial exhaust fan, with a maximum ventilation rate of 12 000 $m^3 h^{-1}$, fixed in a chimney. The system is controlled by a ventilation computer. This computer is connected with the central computer where the ventilation rate and temperature is registered for each chamber.

1.3. Gas concentration measurement: The CH_4, CO_2, N_2O and NH_3 concentrations are measured with an interference-free self-calibrating infrared laser optical-feedback cavity-enhanced absorption spectrometer (OFCEAS) (Morville et al., 2005) (fig. 2). Each second a value is registered. The whole measuring system functions at continuous under-pressure of 110 mbar, created by a 50 µm sonic nozzle at each sampling point. The sampling point for each chamber is situated in the exhaust channels in the ATM module between the impeller and the control valves of each chamber. The background air concentration is measured on two locations in the room near the air inlet. The sampling probes consist of a sonic nozzle preceded by a disposable PVDF prefilter of 0.9 µm and an inline 0.5 µm filter. Each of the eight probes is connected to an eight-channel multi sampler via 25 m of 6-mm PFA tubing. The multi sampler is connected to the gas analyser and successively delivers gas from each probe to the analyser according to a pre-programmed time-schedule.

The whole system is network connected, which enables remote monitoring and intervention. All chambers are monitored by one system, which performs dedicated gas sample conditioning, gas analysis, ventilation regulation, data logging and animal monitoring.

2. RESULTS AND DISCUSSION: Polypropylene was chosen as the base construction material to construct the chamber walls, the feed bins and the manure trays, because it is resilient, resistant, light weight and easy to process and clean. The thermoplastic polymer offers perfect resistance to practically all chemicals, mould, bacteria and corrosion. The smooth, easy to clean surface of the synthetic material is resilient to scratching, wear and heavy blows; it is shock-absorbent and suitable for high-pressure cleaning. PP can be joined by heat fusion. The material provides optimal hygiene is non-toxic, environmentally friendly and pipes and tubes can be easily fitted. The choice for PP for the manure trays has several advantages: they are perfectly integrated in the back wall and easy to handle. The removable manure trays on wheels can be driven on a pallet jack and brought out of the room for manure collection and cleaning with a water hose. In this way, the manure can be removed without opening the doors, which minimises the daily opening time of the chambers. The collected manure can then be transferred into a barrel for simulating manure pits

to study possible shifts in emissions. When desired, the urine and faeces can be collected separately by using a catheter for urine collection. The urine is collected outside the chamber so that it can be acidified without opening the chambers.

The equipment for measuring gas concentrations is configured to work over a broad spectrum, so that the same devices can be used for measurements in both the chambers and in the manure barrels. The detection ranges for CH_4, CO_2, N_2O and NH_3 are set between 0–700 ppm, 0–5000 ppm, 0–5 ppm, and 0-70 ppm, respectively, with corresponding accuracies less than 1% of the full scale; for CH_4 the limit of detection (LOD) is less than 1 ppm. When necessary, the maximum detection limits can be lowered to improve the accuracy of the measurements. The OFCEAS is interference-free and self-calibrating and should have no instrumental drift. The whole measuring system functions at continuous under-pressure, which promotes a low dew point with no risk of condensation in the system. Because methane, carbon dioxide, nitrous oxide and ammonia could be measured continuously and simultaneously with the same laser spectrometer, possible shifts between gases or from the rumen to the manure could be identified. The possibility to calculate emissions of GHG's and ammonia from the animal and its produced manure give a better idea of the real (whole) animal emissions because this method provides a clearer view when there are interactions or shifts between the GHG emissions.

Feeding, milking and cleaning the manure trays is done twice daily at fixed times for dairy cows. It takes two technicians less than one hour to complete all chambers, so emissions can be calculated for 22 hours a day. The animals are visually checked during this visit; however, their conditions are also continuously monitored by the system. When certain parameters, such as temperature or carbon dioxide, exceed the predetermined thresholds, the operator is alerted by phone.

Figure 1. The removable manure tray enables rapid collection and cleaning of manure.

Figure 2. Measuring device: multi sampler (left) gas analyser (right).

CONCLUSION: The total system is primarily designed to monitor methane and other gases from animals and manure. This approach should lead to better estimations of the real animal emissions.

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REPEATABILITY OF ORGANIC MATTER TRANSFORMATIONS AND GASEOUS EMISSIONS DURING WINDROW COMPOSTING

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ABSTRACT: To assess the repeatability of composting, three heaps composed of wheat straw and pig slurry were set up in a gas monitoring enclosure with the same characteristics for volume, mass and composition. Composting lasted 20 days during which NH_3, CO_2, N_2O, CH_4 and N_2O emissions and internal temperatures were measured. Wet weight, dry matter and carbon balances were repeatable with a maximum coefficient of variation (CV) of 1.5%, and core temperatures with a maximum CV of 3% during thermophilic peak. Largely, gaps were observed for the gaseous emissions with a CV of 11%, 9% and 4%, respectively, for NH_3-N, CO_2-C and H_2O cumulated emissions. Mass balances are thus essential to check measured flux of gaseous emissions.

Keywords: composting process, kinetics of OM oxidation, NH_3-CO_2-N_2O-H_2O emissions, repeatability

INTRODUCTION: During composting livestock effluents, organic matter (OM) transformations lead to large gaseous emissions which can harm the environment and decrease the value of the compost as fertilizer (Hassouna et al., 2008). Previous studies have shown that kinetics and total amount of gaseous emissions varied following initial conditions of composting as porosity, humidity and nature and quantity of carbon and nitrogen species (Paillat et al., 2005; Abd el Kader et al., 2007). In these previous experiments, the variability in gaseous emissions and nutrient mass balance are linked to the differences in initial conditions, but also to the variability of biological and physical processes and the uncertainty linked with the experimental device and measurements. A repeatability composting experiment was developed to quantify this variability and uncertainty.

1. MATERIAL AND METHODS:

1.1. Materials and experimental design: Three heaps of the same mix composed of wheat straw (21% of total weight) and pig slurry (79% of total weight) were set up in a gas monitoring enclosure with the same characteristics for weight (517.4 ±0.4 kg per heap), volume (1.37 m^3), dry matter content (29.8%) and free air space (66.4%). Design of the enclosure is described by Paillat *et al.* (2005). Composting was monitored for 20 days before being turned and then fluxes were measured over 5 months for NH_3, CO_2, CH_4 and H_2O and internal temperature in four characteristic zones of the heaps.

1.2. Compost sampling and analysis: To prepare the mixture, all straw was spread on the floor. Pig slurry was then sprayed onto the straw. Next, this preparation was mixed by a rotary cultivator. The three heaps were then constructed simultaneously to control the weight of each. The stockpiling lasted 24 hours so that composting began before the end of handling. Gaseous emissions were measured by the 1312 analyser from Innova (Brüel & Kjaer, Innova, Skordsborgvej 307, Naerum DK-2850).

Concentration measurements were automatically recorded by a computer (RS232 interface). Temperatures inside the heaps, dry and wet air temperatures inside and outside the enclosure, and air speed were recorded every 2 min and averaged every 30 min by two data-loggers (SA70 from AOIP, SAS, Ris-Orangis F-91130, and 21X from Campbell Scientific, Courtaboeuf, F-91967 cedex). After 20 composting days, the three windrows were removed, weighed, mixed and then constructed again. Compost was sampled following the protocol of the French Energy and Environmental Agency (Ademe, BP 90406, Angers F-49004 cedex 01). For each sample, total carbon, total Kjeldhal nitrogen, soluble nitrogen, dry matter content, and Van Soest fractionation were measured. Volumes and weights of the heaps were also measured at the beginning of the experiment and after the 20 composting days.

1.3. Assessment of composting repeatability: To assess the repeatability of the composting process, mean, standard deviation (SD) and coefficient of variation were calculated for the different biochemical and physical characteristics of the three heap replications of the initial mixture and the compost sampled after 20 days.

2. RESULTS AND DISCUSSION

2.1. Kinetics of temperature and gaseous emissions Core temperatures were repeatable with a maximum in the variation coefficient of 3% during the thermophilic peak (figure 1). The maximum CV (7.5%) was observed for the bottom of the heaps during the thermophilic phase. This zone of the heaps is the less aerated area. Therefore, greater heterogeneity exists among the heaps.

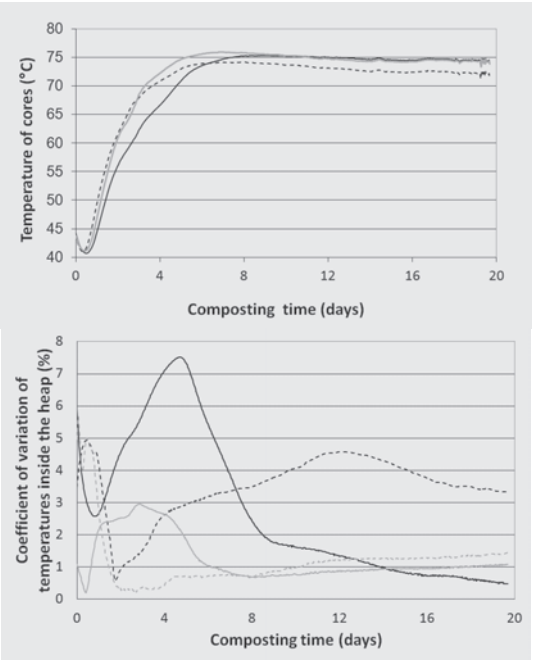

Figure 1. Kinetics of the temperature (left) in the center of heap 1, 2 and 3 (respectively shown by a black line, dashes and grey line). Coefficients of variation (right) of the temperatures measured at the bottom (black line), at the side (black dashes), at the core (grey line) and at the top (grey dashes) of the three replicated heaps.

Characteristic times of the gaseous emissions' kinetics were similar (Figure 2), e.g. time at which the thermophilic peak occurs differed less than 5 hours. However, amplitudes of emissions were quite different: the gaps between maximal and minimal emission values were equal to 16.0%, 17.4%, 22.4% and 32.6% for H_2O, CO_2, NH_3 and CH_4 emissions, respectively. The cumulative emissions of CO_2, H_2O and NH_3 after 3 weeks were, respectively, equal to 24.2 ± 2.0% of initial carbon, 36.7 ± 1.4% of initial water and 12.1 ± 1.3% of initial nitrogen.

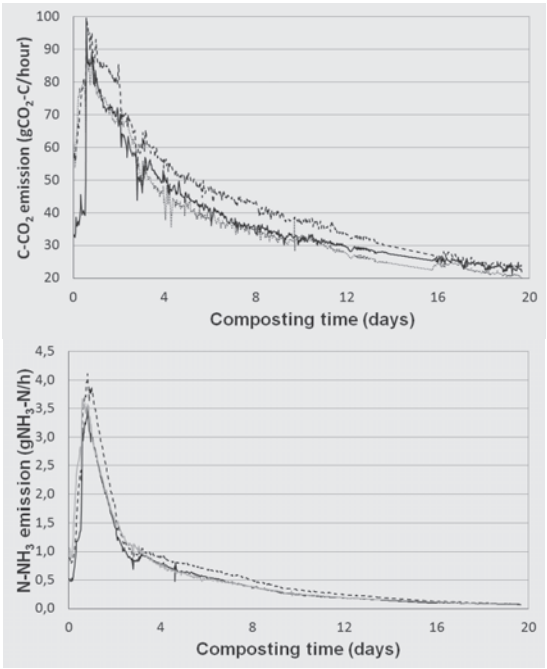

Figure 2. Kinetics of CO_2-C (left) and NH_3-N (right) emissions (respectively, in gCO_2-C/h and in gNH_3-N/h) during the thermophilic phase of composting for heap 1 (bold black line) heap 2 (dashes) and heap 3 (grey line).

2.2 Masses balances:

2.2.1. Elements: After 21 composting days, wet weights of the three turned heaps were similar (332 ±1.9 kg), as well as dry matter content (34.1 ±0.2%). Mass balances were also similar: carbon and water losses were, respectively, equal to 28.4 ± 1.2% of initial carbon and 39.7 ±0.6% of initial water. After 6 composting months, nitrogen losses measured by mass balance were equal to 25.9 ±3.9% of initial nitrogen.

Table 1. Chemical and biochemical composition of the initial mixture and after 20 composting days: mean, standard deviation (SD) and coefficient of variation (CV).

	Initial mixture		Compost sample	
	Mean ± SD	CV (%)	Mean ± SD	CV (%)
WW (kg wet weight)	517.4 ± 0.4	0.1	332.2±1.9	0.6
DM (% wet weight)	29.8 ± 0.9	3.0	34.1±0.3	0.8
TC (% dry weight)	49.4±0.1	0.1	48.1±0.7	1.5
TKN (% dry weight)	1.4±0.1	6.5	#N/A	#N/A
S_{VS} (% dry weight)	30.0±1.1	3.7	37.5±0.9	2.5
HC_{VS} (% dry weight)	27.5±0.4	1.4	16.2±0.1	0.8
C_{VS} (% dry weight)	36.4±0.6	1.8	36.8±0.8	2.2
L_{VS} ((% dry weight)	6.1±0.2	2.8	9.5±0.3	2.7

Element losses estimated by gaseous emissions were underestimated in comparison to estimation by mass balances (table 2). The variation between the three heaps was also greater for gaseous emissions. This can be explained by the more complex protocol to measure gaseous emissions than element concentrations in a compost sample. Gaseous emission measurements thus seemed to give an estimation of the kinetics of transformation in terms of duration. Mass balances enabled correction of the quantity of emitted gases.

Table 2. Losses of carbon, water and nitrogen measured by gaseous emissions and mass balances.

	Gaseous emissions		Mass balance	
	Mean ± SD	CV (%)	Mean ± SD	CV (%)
C-CO_2 (% initial carbon)	24.2±2.0	8.3	28.4±1.2	4.4
H_2O (% initial water)	36.7±1.4	3.8	39.7±0.6	1.5
N-NH_3 (% initial nitrogen)	12.1±1.3	10.9	#N/A	#N/A

2.2.2. Stabilization: The evolution of the size of the Van Soest fractions was homogeneous for the three heaps. The coefficients of variation were similar for the initial mixture and after 20 composting days for each fraction. Van Soest fractionation enables explaining the biodegradability of the matter and kinetics of oxygen consumption (Oudart et al., 2011). The repeatability of the fractions'evolution seemed to show that there were similar flows of microbial growth and oxygen consumption in the three heaps, confirmed by the repeatability of CO_2 emission flow.

2.3. Volume and porosity: Volumes of the three heaps decreased from 1.37 m^3 to 1.13±0.02 m^3 (CV = 1.7%), whereas porosities increased from 66.4% to 74.3±0.4% (CV = 0.5%) after 20 composting days. The evolution of the total volume, volumes of water, air and dry matter of the three heaps had similar behavior. While fabrication of the heaps inevitably differed with heterogeneous repartitions of the matter and the porosity, the global evolution was identical. The local evolution of porosity and volume seemed to have no impact on their global evolution. A similar structuring material with a specific matter density can attempt to understand the evolution of volume and porosity and its potential for maintaining positive aeration conditions.

CONCLUSION: The results of mass balances, characteristic times of emission kinetics and temperature kinetics showed that biological and physical processes were repeatable for a similar composting situation. Mass balances attested that similar quantities of elements (C, N, and H_2O) were lost. Therefore, observed differences for values of fluxes of H_2O and CO_2 were probably mainly due to the uncertainty of measurement. Differences in NH_3 and CH_4 emissions after 20 days were highest and probably due to different distribution of free air space. Mass balances are then essential to check measured fluxes of gaseous emissions.

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A MEASURING STRATEGY FOR INDOOR CONCENTRATIONS AND EMISSION RATES OF PARTICULATE MATTER IN PIG FATTENING FACILITIES

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ABSTRACT: The objective of this study was to develop a measuring strategy for indoor concentrations and emission rates of particulate matter (PM) in pig fattening facilities. The rearing facility used in this study was a conventional (i.e., typical for Europe) housing system for fatteners with a fully slatted concrete floor, housing 104 pigs. Different PM fractions ranging from 0.25 to 32 µm were sampled continuously (1 minute interval) with 2 spectrometers (Grimm 1.109 spectrometers, Grimm Aerosol Technik GmbH & Co. KG, Ainring, Germany) during one fattening period starting from June 24th 2009 until October 23rd 2009. Environmental parameters, such as temperature and relative humidity, were also sampled during the experiment. The sampling position within the animal compartment had a small significant effect on the measured PM concentration. Larger effects were observed for daily variations and variations over the entire fattening period. The contribution of sampling position to the variance of indoor PM concentrations was 6, 4 and 12% for PM_1, $PM_{2.5}$ and PM_{10}, respectively. The effect of daily variation contributed 29, 65 and 58% to the concentration variance, while the effect of variation over the fattening period was 65, 31 and 31% for PM_1, $PM_{2.5}$ and PM_{10}, respectively. Based on these conclusions, a measuring strategy for pig fattening facilities is proposed. For one fattening period, the strategy consists of 4 to 5 specific 48h-sampling periods. This measuring strategy offers the possibility to significantly shorten the total sampling time and to reduce the number of measurements without losing important PM concentration data. This strategy also allows a reconstruction of the evolution of PM concentrations over the entire fattening period.

Keywords: indoor concentrations of particulate matter, emission rates, pig fattening facilities, measuring strategy

INTRODUCTION: Measuring PM indoor concentrations and emission rates from pig fattening facilities is important for evaluating the impact on human and animal health and the environment. Measuring typical indoor PM concentrations and emission rates is time- consuming and expensive. Therefore, most researchers reduce the sampling period to a restricted number of days (Aarnink et al., 2004; Gustafsson, 1999; Haeussermann et al., 2008; Hofschreuder et al., 2008; and others). To generate representative data, these measuring days cannot be chosen at random, but must be carefully selected based on an overall assessment of the temporal and spatial variations of PM concentrations. Furthermore, detailed knowledge about spatial and temporal distribution of PM in pig fattening facilities is useful to detect extreme PM values in the animal house, to optimise ventilation strategies, to design and evaluate efficient PM reduction techniques, and to adequately estimate the impact on human and animal health.

1. MATERIAL AND METHODS:

1.1. Sampling location and instruments: Measurements were performed in a conventional rearing facility for fatteners from June 24th 2009 until October 23rd 2009. The building contained seven compartments with separate deep pits under the slatted concrete floor, containing 104 pigs each. Each compartment had 8 pens, four on each side of a central alley. One compartment was selected for the experiments. Fresh air enters the facility under the slatted floor in the central alley (channel ventilation) and is mechanically extracted via an exhaust ventilator (diameter 0.56 m). The ventilation rate is temperature regulated. Indoor particulate matter was sampled using two Grimm 1.109 spectrometers (Grimm Aerosol Technik GmbH & Co. KG, Ainring, Germany). These instruments were placed in specially constructed iron cages attached to the slatted floor in the middle of the pens. The sampling location varied during the experiment. Measurements were performed at three different heights (animal (0.8 m), human (1.6 m) and ventilation exhaust height (2.4 m) in 6 pens. Additionally, emission measurements were performed in the ventilation shaft using an isokinetic sensor attached to the Spectrometers. During each experiment, two different locations were sampled simultaneously with the two spectrometers. This allowed precise determination of PM concentration variations depending on the location in the stable. On average, the different locations were sampled every two weeks, during a minimum of two days. Ventilation rate and temperature were monitored with a calibrated ventilation fan (type FMS 56, Fancom, Panningen, Netherlands).

1.2. Statistical analysis: Data were analysed based on the hourly averages. All parameters showed a normal distribution based on the Kolmogorov-Smirnov test. The proportion of variance occurring at the different levels of the data hierarchy was evaluated based on a multilevel model MLwiN 2.19 (Centre for Multilevel Modelling, Bristol, UK). Next, differences in time (day number and hour of the day) were analysed by means of repeated measures analysis followed by a Bonferroni post-hoc procedure using SPSS 17.0 (SPSS Inc., Chicago, Illinois, USA). Statistical significance was considered for $p < 0.05$.

2. RESULTS AND DISCUSSION:

2.1. Spatial and temporal effect on PM concentration: Table 1 shows an overview of the relative contributions of sampling location, day in the fattening period and hour of the day, to the variance of the PM concentrations. The spatial position of the instruments had a significant effect on the PM concentration, but compared to daily variations and variations within the fattening period, this effect was small. Occasionally, high PM_{10} concentration differences were observed, probably due to the difference in animal activity between different pens. For each PM fraction, all concentrations measured at different sampling locations were highly correlated (R^2), especially for PM_1 where al R^2 between concentrations measured at different locations were higher than 0.8. The temporal effects on the PM concentrations can be divided into two aspects, i.e., the diurnal variations within one 24-hour day (diurnal variation) and the variations over the whole fattening period (day-to-day variation). Compared to the diurnal variation, the day-to-day variation was twice as high for PM_1, but for $PM_{2.5}$ and PM_{10}, the opposite was observed (Table 1).

Table 1. Relative contribution of the sampling location, day in the fattening period and hour of the day (%) to the variance of the PM concentrations.

PM_1			$PM_{2.5}$			PM_{10}		
Location	Day	Hour	Location	Day	Hour	Location	Day	Hour
6.2	64.7	29.1	4.0	31.5	64.5	11.8	30.5	57.7

Within one day, a number of statistically different periods can be distinguished depending on the PM fraction. For PM_1, two high concentration periods were observed along with one low concentration period. For $PM_{2.5}$ and PM_{10}, two high and two low concentration periods were observed. An overview of these high and low concentration periods and their respective times (local time) for every PM fraction are shown in Table 2.

Table 2. The high and low concentration periods for the respective PM fractions.

Fraction	High concentration period	Low concentration period
PM_1	7-12 am and 6-8 pm	9 pm - 7 am
$PM_{2.5}$	6-10 am and 5-7 pm	9 pm - 4 am and 12 am - 2 pm
PM_{10}	7-10 am and 5-7 pm	9 pm - 4 am and 12 am - 1 pm

During the fattening period, PM concentrations increased, with a peak around day 94 and slightly decreasing concentrations afterwards. For PM_1 and $PM_{2.5}$, significantly higher concentrations were observed during the first 10 days of the fattening period. This was probably due to the feed type supplied at that moment (finer grained piglet meal). Overall, significant differences over the whole fattening period were observed for all PM fractions (Fig. 1). For PM_1 and $PM_{2.5}$, four such different periods were observed in the fattening period, for PM_{10} three periods were observed.

2.2. Proposed sampling strategy: Based on the spatial and temporal distribution of the three PM fractions, a sampling strategy is proposed which enables reconstruction of the evolution of PM concentrations over the entire fattening period. This includes at least one day of PM sampling during each four measuring periods for a fattening period of 120 days. As it can be of interest for impact evaluation towards human or animal health, a fifth measuring period can be added around day 94, when the highest concentrations were measured in this fattening period. The timeline of the measuring strategy with the different measuring periods is shown in Figure 1. Occasionally, significantly different concentrations were measured on two consecutive measurement days. Therefore, it is suggested to measure during two consecutive days for each measuring period. The spatial distribution had a limited effect on the measured PM concentrations. The PM concentrations measured at different locations in the stable were highly correlated. Therefore, one sampling location is sufficient. The sampling location can be selected based on the measurement scope. For example, when the effect of PM concentrations on animal health and productivity needs to be investigated, sampling at animal height is recommended. For regulatory reasons, e.g. determination of emission factors, it is advisable to sample PM concentrations near or in the ventilation shaft. To account for seasonal variations, as described by Jacobson *et al*. (2004), Keck *et al*. (2004), and Koziel *et al*. (2004), it is advisable to sample PM in at least two fattening periods in the same barn and during two different seasons.

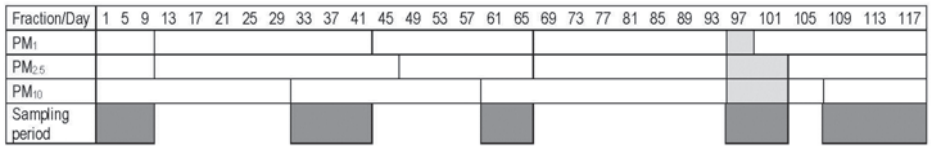

Figure 1. Proposed measuring periods (dark gray blocks) based on analysis of the variation of PM concentrations during one fattening period. Periods with significantly different PM_1, $PM_{2.5}$ and PM_{10} concentrations are indicated with vertical lines. The light gray blocks indicate the periods with the highest concentrations.

CONCLUSION: The spatial and temporal effects on PM_1, $PM_{2.5}$, and PM_{10} concentrations in a fattening facility were examined. Both effects can vary significantly according to the PM fraction. Variation analysis showed the importance of sampling during different periods over the whole fattening period. Based on this analysis, a measuring strategy was proposed for future research concerning the impact of PM on the environment, and on human and animal health.

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COMPARISON OF METHANE EMISSIONS FROM CATTLE ASSESSED BY THREE DIFFERENT METHODS: OPEN-CIRCUIT RESPIRATION CHAMBERS, IN VITRO GAS PRODUCTION AND THE CO_2-METHOD

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ABSTRACT: Different methods exist for estimating methane production by ruminants with different optimal applicability. The objective of this study was to compare the estimates of methane emissions from cattle resulting from 3 different measuring techniques: Open-circuit respiration chambers (RESPT), In vitro gas production (IVGPT) and the CO_2-technique (CO_2T). The techniques were applied in three separate experiments but with the exact same feed rations containing 35% DM of wheat (W), Molasses (M) or molasses+0.9%DM sodium bicarbonate (MBic). Significant differences were found between methods when comparing the values of ml CH_4/g DM. The respiration chambers gave the highest values and IVGPT the lowest. Within the IVGPT and RESPT experiments, significant differences were found among the three rations, with W giving less CH_4/g DM than molasses rations. For CO_2T, the same numerical ranking was observed but the differences were not significant. The residual model errors were of the same magnitude for all three methods. It is concluded that the absolute values of CH_4 production differ significantly among the three experiments. This may be caused by the measurement techniques or/and the differences in cows. The ranking of rations (W<M=MBic) was the same for all methods.

Keywords: CH_4, cattle, measuring method, comparison

INTRODUCTION: Numerous methods have been developed to estimate the actual emissions of livestock and evaluate potential methods for methane mitigation. They are based on different principles and have different optimal applicability (Storm et al., 2012). Two relatively new approaches for estimating methane emission from ruminants are modified *in vitro* gas production (IVGPT) techniques (Bhatta et al., 2008) and the CO_2-technique (CO_2T) (Madsen et al., 2010). These methods are fundamentally different from the traditional open-circuit respiration chamber technique (RESPT): IVGPT simulates the ruminal fermentation of feed under controlled laboratory conditions, while CO_2T makes spot measurements of the CH_4/CO_2 ratio in the exhaled air of ruminants and multiplies it with the estimated total CO_2 production. Few studies have been published on the comparison of these new methods with RESPT. Comparing methods used in separate studies is complex due to differences between feeds and animals used in the experiments. The aim of this study was to compare the estimates of methane production resulting from three individual experiments employing RESPT, CO_2T or IVGPT, but with the exact same feed rations.

1. MATERIALS AND METHODS: Three separate experiments were conducted employing each method and different animals. The same three feed rations were used in all experiments. They all consisted of grass-clover silage (49% of dry matter (DM)) and soy bean meal (14 % of DM) supplemented with 35 % (DM) of either crushed wheat (W), sugar beet molasses (M) or sugar beet molasses with sodium bicarbonate (0.9 % of DM) (MBic). The chemical composition of the rations is presented in Hellwing et al. (2012). All portions of the feed rations were mixed from the same

batches of ingredients at the experimental farm facilities of Aarhus University, Foulum, Denmark. All gas volumes are reported at standard temperature and pressure (0^oC, 100 kPa).

The RESPT experiment included a fourth ration where the 35 % (DM) supplement was sodium-hydroxide treated wheat. It was conducted according to a 4x4 Latin Square design with 4 lactating Holstein-Friesian cows. The average body weight (±SD) was 570±36 kg, average dry matter intake (DMI±SD) 18.0±1.6 kg/d, and average milk yield 21.4±6.1 kg ECM/d. The mixed rations were prepared once daily and fed ad libitum with two feedings a day. In each period the cows were subjected to a 3-week adaptation period before methane emission was measured in open-circuit respiration chambers over 4 consecutive days. For a detailed description of the experiment see Hellwing et al. (2012).

The CO_2-technique was applied to 3 Dexter heifers in conjunction with measurements of their CO_2-production in traditional open-circuit respiration chambers. The experiment was conducted as a 3x3 Latin Square with 3 periods consisting of 2 weeks' adaptation followed by one week where measurements were conducted. Each animal was monitored with CO_2T for one 22 h period. All feed for the entire experiment was prepared once from the same batches of ingredients as used in the RESPT experiment, and at the same facilities. The TMRs were immediately vacuum-packed in portions for 1 day, frozen, and transported to the University of Copenhagen. Each portion was thawed at room temperature overnight before being feed ad libitum with one daily feeding. The average BW (±SD) of the heifers was 226±11 kg and the average DMI (±SD) was 5.1±0.3 kg/d. For further description see Haque et al. (2012).

For IVGPT, feed samples from the CO_2T-experiment were dried (60^oC) and milled (1 mm mesh; Cyclotec 1093 sample mill, Foss Analytical, Hilleroed, Denmark). Portions of 0.500±0.01g of feed were weighed into F57 filter bags (Ankom Technology, Macedon, NY, USA). After sealing, the filter bags were put into 100 ml Duran bottles fitted with automatic wireless *in vitro* gas production modules (Ankom Technology, Macedon, NY, USA). Rumen fluid was obtained from two rumen fistulated jersey heifers at UCPH. The heifers were on a diet of hay supplemented with grazing. Buffered rumen fluid inoculum was prepared according to the directions of Menke and Steingass (1988). Portions of 90 ml mixed inoculum fluid was added to each IVGPT module, which were closed, fitted with evacuated airtight gasbags (FlexFoil, 1 L; SKC Ltd, Dorset, UK) on the outlets and incubated at 39^oC for 48 hours with gentle stirring (20 rpm). Gas pressure was detected every 5 minutes and gas released when the pressure exceeded 3.45 kPa above atm. pressure. After incubation, the volume of total gas produced was calculated by applying the ideal gas law. The percentage of CH_4 in the released gas was measured by gas chromatography (Agilent 7820A GC, Agilent Technologies, Santa Clara, USA; equipped with a TCD detector, a HP-PLOT Q column (30 m x 0.53 mm x 40 μm) and employing H_2 as carrier gas).

Each experiment was analyzed with individual statistical models to account for individual study design: RESPT by a MIXED model in SAS with carbohydrate source, ration pH, carbohydrate*pH interaction and period as fixed factors and cow as random factor (Hellwing et al. 2012). CO_2T was analyzed by a GLM model in SAS with cow, period and ration as fixed effects and by a MIXED model differing only in cow as a random factor. For IVGPT, the effect of ration was evaluated by a linear model in R combined with multiple comparisons of means by Tukeys contrasts. Methods were compared within each ration by the same approach in R. Significance level was set at $P<0.05$.

2. RESULTS AND DISCUSSION: The raw values for ml CH_4/g dry matter, as assessed by each of the methods, are plotted in Figure 1, and the mean values including results of the statistical comparisons are presented in Table 1. For IVGPT, three values were omitted from the statistical analysis: two due to module failure during incubation; the third was assessed as an outlier on the basis of a Cooks distance above 0.5 combined with deviation from a normal distribution according to Shapiro-Wilk normality test in R.

All three methods resulted in lower values of CH_4 production per gram DM for the W ration than for the two molasses rations. There was a significant difference between starch-based and sugar-based rations in the RESPT and IVGPT experiments (P=0.03 and P<0.001). This supports other findings that starch results in less ruminal CH_4 than sugar. No significant differences were found between feed rations in the CO_2T experiment. This is probably due to the weak statistical strength of the 3x3 Latin Square design. The variation between heifers was almost as high as the variation between diets and no significant differences could therefore be observed.

The root mean square errors of the three statistical analysis (Table 1) are; however, of the same magnitude, indicating that the variation within experiments, caused by random variations, e.g. in the measurement instruments, are similar. The slightly higher RMSE for CO_2T can be explained by the partial sampling of exhaled breath with this technique (Haque et al., 2012). Additionally, is fairly easy to include more animals/units in both CO_2T and IVGPT experiments, making the statistical comparisons between treatments stronger.

Within each feed-type the comparison of methods showed significant differences. RESPT consistently gave higher estimates than CO_2T. For M and MBic, rations the difference was significant (P<0.01), although for W it was not (P=0.08).

Table 1. Mean values of ml CH_4/g DM (± standard deviation) for each combination of method and ration followed by results from the statistical analysis for effect of ration within methods.

	Mean ml CH_4/g DM					
Method	Wheat	Molasses	Molasses+Bic	RMSE[a]	P_{ration}	$P_{carbohydrate}$
RESPT	32.1	35.9	34.6	1.9	-[c]	0.03
IVGPT	15.8	23.8	24.7	1.5	<0.001	-
CO_2T	26.4	28.5	29.8	2.6	NS	-

[a]Root mean square error/residual standard error of the model used within each technique.
[b]This experiment was conducted as a 4x4 latin square with at fourth ration included.
[b] - = not applicable

CO_2T, in turn, gave significantly higher estimates for CH_4 production/g DM than IVGPT (P=0.004, 0.05, and <0.001 for W,M, and MBic). These differences may be due to other factors related to the individual experiments than the technique used for measuring CH_4 production. While care was taken to use the exact same feed rations in all experiments, there were large differences between the cows used and the experimental designs due to practical constraints. The relatively low gas production measured by IVGPT may also be related to the use of feed dried at 60°C (Parissi et al., 2005).

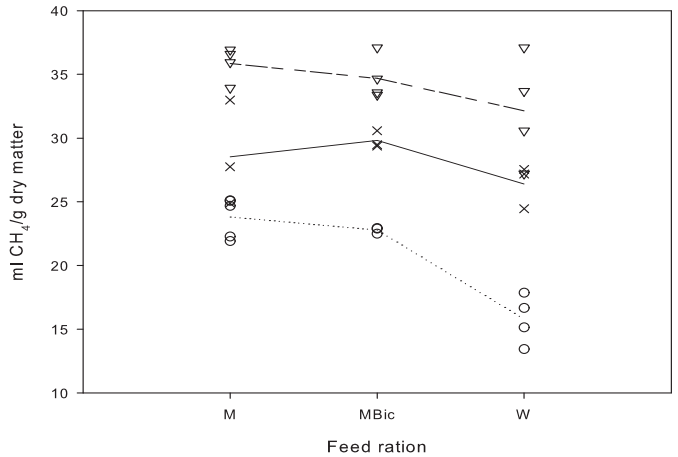

Figure 1. Production of methane per gram dry matter intake/incubated as assessed by the CO_2-method (×,—), in vitro gas production technique (○, ¨) and open-circuit respiration chamber technique (▽, ---) for three cattle rations differing in carbohydrate composition of the concentrate. The lines connect the mean values for each method.

CONCLUSION: In two out of three experiments, the wheat-based ration(s) resulted in a significantly lower CH_4-production per gram DM than the molasses-based rations. Within feeds, the absolute values were significantly different among methods with RESPT > CO_2T > IVGPT. Therefore, absolute values obtained by any method must always be interpreted with care.

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ACCURACY OF LAGOON GAS EMISSIONS USING AN INVERSE DISPERSION METHOD

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ABSTRACT: Measuring gas emissions from treatment lagoons and storage ponds poses challenging conditions for existing micrometeorological techniques because of non-ideal wind conditions. These include those induced by trees and crops surrounding the lagoons, and lagoons with dimensions too small to establish equilibrated microclimate conditions within the water boundary. Using a synthetic floating emission source with known emission rates from an irrigation pond, this study evaluated the accuracy of an emerging backward Lagrangian stochastic (bLS) inverse-dispersion technique to measure lagoon emissions. The measured parameters were wind statistics and path-integrated concentrations (PICs) from multiple locations. Anemometers were located on the upwind, downwind, side berm parallel to wind, or directly above pond water surface. PICs were monitored within the pond and on the downwind berm. Additionally, the berm surface was deliberately roughened during the summer by placing pine straw bales along the berms to simulate vegetation growth. The accuracy of the inverse-dispersion technique was significantly affected by the location of the 3D sonic anemometers. Generally, using an anemometer located on the berm produced more accurate results than using an anemometer located directly above water surface. The total average accuracy of all combinations of anemometer location and PICs for both smooth and rough berm surface conditions was 0.77 ± 0.23 ($N = 398$). This lagoon study showed an accuracy level similar to environments that meet the ideal assumptions of the inverse-dispersion model, thus, demonstrating the robustness of the inverse-dispersion technique even in non-ideal settings.

Keywords: waste lagoon emission, backward Lagrangian stochastic, accuracy, optimal sensor location

INTRODUCTION: Animal waste lagoons and storage ponds have been undesired point sources for odor, ammonia, and greenhouse gas emissions (Liang et al., 2002; Ro et al., 2008). Thus, accurate assessment of these trace gas emissions is important for proper planning and management of animal wastes. One of the assessment methods, the bLS technique, measures the concentration rise downwind of a source, and with the aid of an atmospheric dispersion model (and wind information) one infers the source emission rate (Flesch et al., 2005; Gao et al., 2009, 2010; Harper et al., 2010; McBain and Desjardins, 2005; Ro et al., 2011; Ro et al., 2012). The advantage of the technique is simplicity and flexibility in terms of field measurements. As with most other micrometeorological methods, one main limitation of the bLS technique is that one must assume idealized wind flow over the measurement site (i.e., flat and homogeneous terrain) – an assumption seriously violated at many waste lagoons.

An important question is whether the bLS technique provides accurate emission measurements in a lagoon environment, and to what extent the accuracy depends on sensor placement. Ro et al. (2012) recently reported an accuracy level for the bLS

emission measurements in lagoon environments that was similar to ideal environments that meet the theoretical assumptions of the inverse-dispersion model. Although they examined the effect of 3-D sonic anemometer location on accuracy, they used only one location for PICs measurements. The objective of this study was to evaluate the optimal location for both wind and concentration measurements within the lagoon environment.

1. MATERIAL AND METHODS: This study was conducted on a rectangular irrigation pond (59 m x 68.5 m) at the USDA-ARS Coastal Plains Soil, Water and Plant Research Center in Florence, SC (N 34°14.741' and W 79°48.605'). A floating perforated pipe network was used as a synthetic distributed lagoon emission source. Bales of pine straw (0.25 H x 0.4 W x 0.7 L m) were secured midway up the side slopes along the upwind and downwind berms to create an artificial "rough" side slope to simulate berms frequently found with heavy vegetation growth in warm climate regions. Pure methane gas was used as a test gas, and its true emission rate was calculated from weight loss during experiments. A 3-dimensional sonic anemometer (CSAT3, Campbell Scientific, Inc.) was used to measure wind statistics at 20 Hz. The open-path tuneable diode laser absorption spectrometers (TDL, GasFinder2.0 for CH_4, Boreal Laser Inc., Spruce Grove, Canada) and retroreflectors were used to measure PICs. They were measured along the downwind berm, pond middle, and downwind water edge of the pond, as shown in Figure 1. The study pond, having steep berms and bordered by corn fields and trees, would be characterized by a complex wind environment (highly different from that assumed in the bLS calculations). A more detailed description of the pond and instrumentation can be found in Ro et al. (2012).

Methane PIC data was averaged at 15 minute intervals. For each 15 minute period, the background concentrations were subtracted from the downwind concentrations. This net PIC data, along with the wind statistic data collected by the anemometers, were used as inputs to the Windows-based bLS computer model, WindTrax 2.0 (Thunder Beach Scientific, http://www.thunderbeachscientific.com/, accessed on October 3rd, 2008). For each measurement period, the bLS model calculated the upwind trajectory of fifty thousand gas "particles" passing through the TDL path and determined the relationship between downwind concentration and the lagoon emission rate. The following data-filtering criteria were used to avoid error-prone observation periods (Ro et al., 2012).

- footprint (FP) $\geq$ 20%
- Obukhov stability length scale, $|L| \geq 5$ m
- frictional wind speed, $u^* \geq 0.22$ m/s

The accuracy of the inverse-dispersion technique was calculated as:

$$\text{accuracy} = Q_{bLS}/Q \quad (1)$$

where Q = actual emission rate (g/s), Q_{bLS} = calculated emission rate via inverse-dispersion technique (g/s). The central tendency and its precision of the accuracy were represented with arithmetic averages and standard deviations (given as ± values in the subsequent accuracy summaries). An unpaired t test with Weltch's correction was used for comparing two values. All statistical tests were performed using GraphPad Prism 5.04 (GraphPad Software, Inc., La Jolla, CA).

2. RESULTS AND DISCUSSION: The average accuracy (Q_{bLS}/Q) of all the runs was 0.77 ± 0.23 (N = 398). As shown in Figure 1, these runs included situations where the sonic anemometer was located at the upwind, side, downwind berms or about 1 m above water surface in the pond; and where the berm surface was either smooth or rough. Additionally, the PICs were obtained from middle of the pond, downwind edge of the pond, or downwind berm. The accuracy of the bLS technique using the wind data obtained from the 3-D sonic anemometer located on the berm (upwind, side, or down berm of the pond) was significantly better ($P < 0.05$) than using the wind data obtained from the 3-D sonic anemometer directly above water surface, as shown in Table 1 (i.e., 0.81 ± 0.24 vs. 0.72 ± 0.21). Using the berm 3-D sonic anemometer, the PICs obtained from both downwind of the pond and on the berm yielded the same 88% accuracy, which were significantly better ($P < 0.05$) than the PICs obtained in the middle of the pond. Using the pond 3-D sonic anemometer, the PICs obtained downwind of the pond provided better accuracy (i.e., 82%) than that obtained from downwind berm or pond middle. Interestingly, regardless of the 3-D sonic-anemometer location, the PICs obtained from the middle of the pond yielded the poorest accuracy.

Among the accuracies with the 3-D sonic anemometer located on berm (upwind, side or downwind), the upwind berm location yielded the best results where there was a clear fetch. Since the upwind berm 3-D sonic anemometer does not see the berm (the anemometer is influenced by the properties of the upwind corn field), the accuracy did not depend on the berm surface roughness. Using the upwind berm 3-D sonic anemometer and downwind berm PIC yielded an accuracy of 0.98 ± 0.21(N = 42), while the upwind berm 3-D sonic anemometer and downwind pond PIC yielded 0.99 ± 0.25 (N = 33). Using the side berm 3-D sonic anemometer, the accuracies using PICs from downwind berm, downwind pond, and middle of pond were 0.79 ± 0.20, 0.75 ± 0.13, and 0.63 ± 0.17, respectively. Because the downwind berm 3-D sonic anemometer sees the berm surface directly ahead, the berm surface roughness significantly affected accuracy. Among the downwind 3-D sonic anemometer and the PICs obtained from the downwind berm, the smooth berm surface produced a significantly more accurate emission rate (0.91 ± 0.12) than rough berm surface (0.81 ± 0.06). Among the pond 3-D sonic anemometer (both smooth and rough berm surface), those of the PICs obtained from the downwind pond produced an accuracy of 0.82 ± 0.22. The PICs obtained from the downwind berm produced an accuracy of 0.72 ± 0.20, and the PICs obtained from the middle of pond yielded an accuracy of 0.64 ± 0.19.

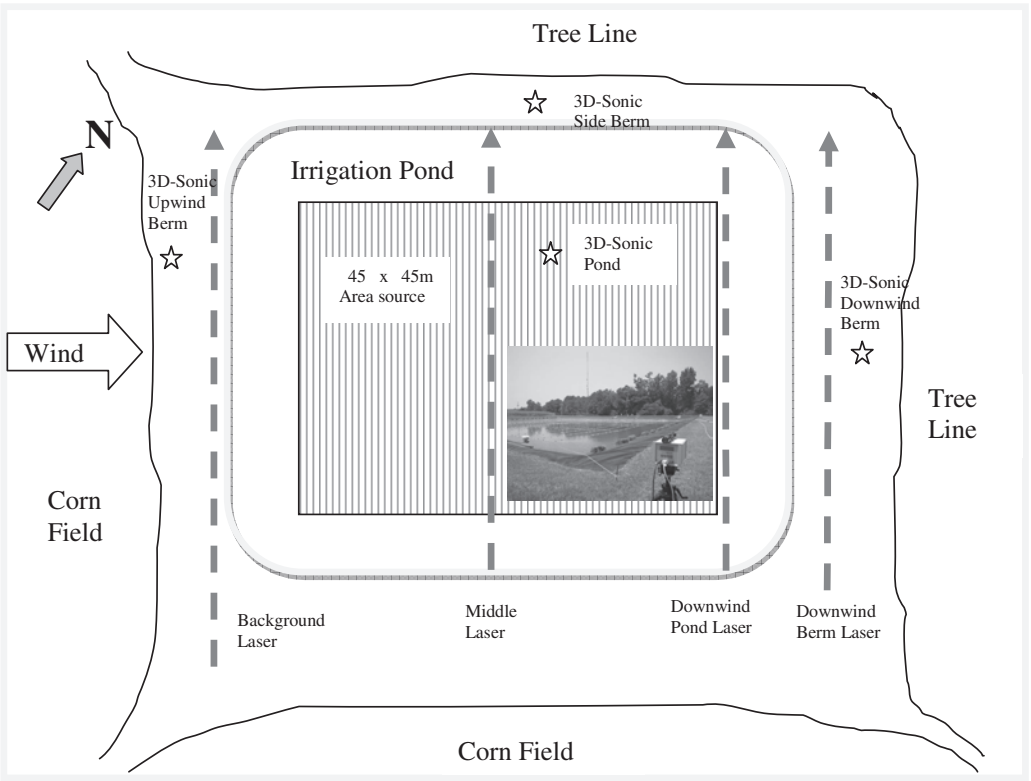

Figure 1. Experimental layout of the pond, distributed source, and sensor locations.

Table 1. Accuracy of the bLS technique using wind and concentration sensors at various locations.

3D-Sonic Anemometer Location	TDL Location (PIC)	Q_{bLS}/Q	No. Datasets
Berm (upwind, side, or downwind)	middle of pond	0.63 ± 0.20	65
	downwind of pond	0.88 ± 0.23	62
	downwind berm	0.88 ± 0.21	104
	All	0.81 ± 0.24	231
Pond	middle of pond	0.64 ± 0.19	56
	downwind of pond	0.82 ± 0.22	53
	downwind berm	0.72 ± 0.20	58
	All	0.72 ± 0.21	167

CONCLUSION: The accuracy of the bLS inverse-dispersion technique in a waste lagoon setting was evaluated using an irrigation pond with a fabricated floating emission source. The overall accuracy of the inverse-dispersion technique was 0.77 ± 0.23, but the accuracy of the technique was significantly affected by the location of the 3D sonic anemometers and PIC measurements. Using an anemometer located on the upwind berm with downwind berm PIC, or using an anemometer directly above pond water surface along with the PICs from the downwind pond, produced the most

accurate results (98% or 99%, respectively). Our results suggest that the preferred locations for an anemometer and tunable diode laser in a lagoon study are on the upwind berm (provided that the fetch is free from tall vegetation) and downwind berm, respectively.

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

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ABSTRACT: In the ten years before the EMILI 2012 symposium, gaseous losses from animal farms became increasingly important in the media. The paradox of this tendency was the great number of publications, scientific or not, even though the emissions of most animal farms had never been measured. Therefore, the development of reference tools to measure greenhouse gas and ammonia emissions was important. Such tools allow recognition and remuneration of the best practices and equipment. Accordingly, ADEME funded an international project associating several research and development organizations involved with the animal production chain. The project proposed an initial set of 18 procedures to measure ammonia and greenhouse gas emissions from animal houses and manure stores. These were adapted to the diversity of animal farms found throughout the world. Some methods were compared during a "building" and a "liquid manure" experiment. Results showed a high difference among methods (ca. 80%), much higher than the estimated uncertainty. Associating independent emission measurements, together with a mass balance of the system, is necessary for the reliability of further results. However, previously published references lack uncertainty estimates of measurements that conform to GUM 2008. In the coming years, this is one of the major concerns for measuring emission factors. Uncertainty estimates should depend on the measurand (temporal: hourly, per batch, yearly; spatial: animal, house, national) and include the uncertainties associated with system representativity and temporal interpolation.

Keywords: measuring method, NH_3, GHG, dust, uncertainty

INTRODUCTION: Gaseous losses on animal farms are receiving increasing importance in the media. The paradox of this tendency is the great number of publications, scientific or not, even though the emissions of most of the animal farms were never measured. Therefore, IPCC guidelines for emission inventories are based on many references (IPCC, 2006), but the uncertainty in emission factors remains high: 50% in France (CITEPA, 2012). Therefore, development of measurement tools for greenhouse gas and ammonia emissions is important. The quantification of emissions also enables recognition and remuneration of the environmental performance of animal farms. Thus, farmers will be encouraged to adapt their practices. The tools could offer realistic reduction objectives without waiting until negative effects are so high that expensive regulation becomes inevitable. Accordingly, ADEME funded an international

project associating several research and development organizations involved in the animal production chain.

The project's objective was to propose an initial set of reference procedures for measuring ammonia and greenhouse gas emissions from animal houses and manure stores. These were adapted to the diversity of animal farms found throughout the world.

1. MATERIAL AND METHODS: The project was based on the experience of the partners in measuring of gaseous emissions on animal farms and exchanges between them. It comprised three phases: reviewing existing methods, describing some methods in detail, and evaluating the ability to apply the methods in various countries. During the second phase, different measuring methods were compared in two experiments, one with liquid manure storage and one in a poultry house.

The storage experiment occurred at the IFIP experimental station in Romillé, France. Two tanks were used that contain approximately 10 m^3 of slurry produced during a standard batch of growing-finishing pigs. One tank was covered with a greenhouse equipped with a calibrated fan, allowing accurate ventilation measurement around the tank. The other tank was equipped with a dynamic chamber, and measurements were compared with emissions measured with a tracing gas. The mass balance of water, carbon and nitrogen was also measured.

The housing experiment occurred in a commercial house equipped with natural ventilation automatically regulated with motorized curtains and temperature sensors. The broilers were reared from 20 November 2008 to 19 January 2009. Air temperature and humidity were measured from 15 November to 21 January. Gas concentration measurements started 29 November and ended 18 January. Ventilation was measured indirectly using two tracing methods: one using assumptions on heat production of animals and manure, the other based on a measured flux of SF_6 injected homogeneously into the house for 20 days between 29 November and 27 December. The mass balance of the batch was also measured. A simplified method suited to batch emissions based on intermittent measurements of the ratio of concentration gradients between inside and outside the house was also applied and compared to the emissions calculated with ventilation measurements. An indirect method based on reverse modelling was also applied from 11-18 December and compared to previous hourly emission measurements based on heat production or SF_6 tracing. Dust concentrations and particle-size distributions were also measured inside and outside the house.

2. RESULTS AND DISCUSSION:

2.1. Methods described: The following methods were described within the project (see http://www4.inra.fr/animal_emissions_eng/Results) for further details:

1. measuring the mass balance deficit of manure storage;
2. measuring emissions of ammonia (NH_3), nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2) of liquid manure storage with a dynamic chamber;
3. measuring the emissions of NH_3, N_2O, CH_4 and CO_2 of liquid manure storage with a tracing gas (SF_6);
4. measuring emissions from the mass balance deficit of carbon for pig housing;
5. measuring emissions from the mass balance deficit of carbon for meat poultry housing;
6. measuring emissions from the mass balance deficit of carbon of laying hen housing;
7. measuring emissions from the mass balance deficit of carbon of dairy cow housing;

8. calculating gas emissions using continuous measurements and a model calibrated with intermittent measurements of concentrations for animal housings;
9. calculating ammonia emissions using continuous measurements and a model calibrated with intermittent measurements of emissions for liquid manure storage;
10. measuring ventilation with an anemometer in housings with mechanical ventilation;
11. measuring ventilation with a CO_2 budget in animal housings regardless of ventilation type;
12. measuring ventilation with the heat balance of the animal house;
13. measuring ventilation with SF_6 in the animal house;
14. measuring emissions by using ventilation measurements in the animal house;
15. measuring ammonia emissions using the inversion of a stochastic Lagrangian model;
16. measuring ammonia emissions using the inversion of a Gaussian model;
17. generating a selected ammonia concentration and measuring it using bubbling;
18. calculating the uncertainty in gaseous emission measurements from animal housings or manure storage.

Methods 1, 2, 3, 9 and 18 were applied in the liquid-manure storage experiment and methods 5, 11, 12, 13, 14, 15, and 16 were applied in the housing experiment.

2.2. Method comparison: Both experiments, with liquid manure storage and broiler housing, showed high differences between methods. Comparison with mass balance results required interpolation in the case of continuous measurements (Figure 1). For the batch, nitrogen loss was 771 kg N (N loss = 27% N feed). Measured ammonia emissions were 11% (method 5) or 16% (method 12) of N feed. Denitrification could explain the gap due to observed N_2O emission. Uncertainty was estimated for NH_3 emissions from liquid manure (methods 9 and 18) and was usually below 10%. This could not explain the high gap between emission measurements and the mass budget (observed NH_3 emission less than 50% of nitrogen loss, without significant N_2O emission).

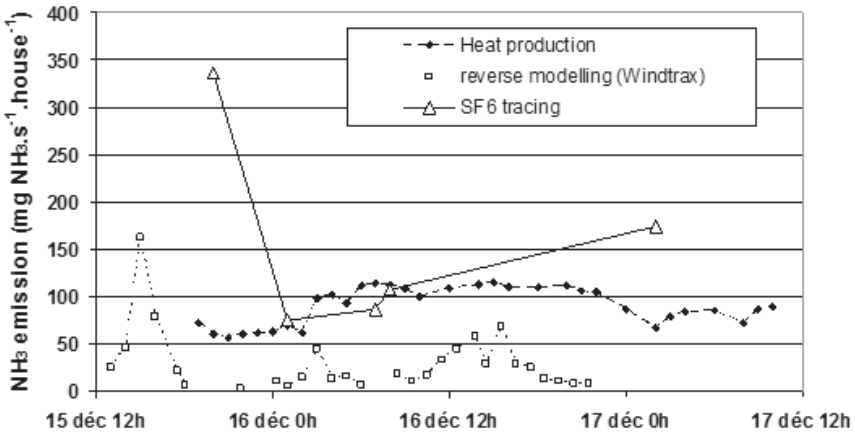

Figure 1. Ammonia (NH_3) emission observed with 3 methods during a broiler batch in a naturally ventilated house in France.

CONCLUSIONS: This project showed that comparing methods, comparing emissions to mass budgets, and repeating measurements should be performed to assess the repeatability and representativity of emission measurements for housing and manure

storage. Emission estimates, based on the regular measurement of gas concentrations inside and outside the houses, constitute one of the rare low-cost methods that can be used regardless of whether animal houses are naturally or mechanically ventilated.

The estimation of uncertainty associated with measurements seems a major omission in previously published references. Complete use of GUM 2008 will be a major issue in the coming years for measuring emission factors. Uncertainties due to air heterogeneity, gas interferences, or calibration are rather simple to associate with continuous measurements. It becomes less straightforward when measurements are intrusive (chamber), when it is necessary to evaluate uncertainties due to representativeness of spatial sampling or temporal interpolation (e.g. intermittent measurements with high climate influence) or to include the effect of variability due to animals, weather, or farmer practices.

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DETERMINATION OF ENTERIC METHANE EMISSION BY SF_6 TRACER TECHNIQUE: PERMEATION TUBES MUST BE CALIBRATED AFTER INCUBATION IN THE RUMEN FOR AN ACCURATE QUANTIFICATION

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ABSTRACT: The sulphur hexafluoride (SF_6) tracer gas technique is particularly adapted to measure enteric methane in grazing ruminants. For accurate measurements, knowing the release rate of SF_6 (RR_{SF6}) from permeation tubes is essential. The specific RR_{SF6} of each tube is determined in a dry environment before introduction into the rumen. RR_{SF6} decreases after incubation in the rumen over long periods but it is not known how to consider this decrease. In this study, the RR_{SF6} from new permeation tubes was monitored before and after repeated incubations in different liquid environments. Twenty permeation tubes were calibrated by repeated weighing for 6 weeks and allocated into two homogeneous groups based on their RR_{SF6}. Tubes were incubated in a cow rumen (n= 12; RR_{SF6} = 1.720 ± 0.212 mg/day) or in a 39°C water bath (n= 8; RR_{SF6} = 1.676 ± 0.338 mg/day) during three repeated 15-day periods. Between incubation periods, RR_{SF6} of each tube was determined again. The RR_{SF6} of permeation tubes averaged, respectively, 1.458 ± 0.156, 1.413 ± 0.099, 1.404 ± 0.215, after the three successive rumen incubations and 1.512 ± 0.159, 1.501 ± 0.139, 1.482 ± 0.168, after incubations in water. The RR_{SF6} decreased only after the first incubation for the two environments tested (*P<0.0001)*. This decrease was numerically higher for the rumen content than for water (15% vs. 9%, respectively). This result indicates that calibrating permeation tubes after an initial incubation in a liquid environment, preferably in the rumen, improves the accuracy of enteric methane measurement using the SF_6 tracer technique.

Keywords: methane, permeation tube, release rate, rumen, SF_6 tracer gas

INTRODUCTION: Sulphur hexafluoride (SF_6) gas is used as a tracer to estimate individual methane (CH_4) emissions from ruminants (Johnson and Huyler, 1994). The SF_6 is loaded in a permeation tube and gas release rate (RR_{SF6}) is determined gravimetrically before introduction into the animal. When permeation tubes are introduced into the rumen, SF_6 is eliminated by eructation and exhalation in a similar way as CH_4 and other gases produced during feed fermentation. Gas samples are collected from around the nostrils and mouth of the animal and analyzed by gas chromatography. Methane emission is calculated using the known RR_{SF6} from the permeation tube and the ratio of SF_6 to CH_4 in the breath sample collected: CH_4 (g/d) = RR_{SF6} (g/d) × $[CH_4]/[SF_6]$. In this tracer technique, the RR_{SF6} is an essential value to calculate CH_4 emissions. Each tube is individually prepared and has an intrinsic RR_{SF6} determined by gravimetry in a dry environment. The RR_{SF6} is constant during calibration under dry laboratory conditions and it is expected that it would remain similar when tubes are inside the animals. However, it is difficult to check the RR_{SF6} in the rumen unless experimenting with animals fitted with ruminal cannula or when animals are slaughtered at the end of measurements. Lassey et al. (2001) showed a RR_{SF6} decreases after a long incubation period in the rumen. To adjust for this deviation in trials lasting extended periods of time, these authors proposed to recover permeation tubes after the experiment or to use sibling tubes kept at 39°C throughout the experiment and adjust RR_{SF6} by using quadratic equations. For shorter experiments, no adjustment was recommended[2]. However, we observed a systematic decrease in the pre-

calibrated RR_{SF6} value by 17 ± 6% (n=73) even after short periods (25 days) in the rumen (Rochette, unpublished data). To better understand this phenomenon, the RR_{SF6} from permeation tubes was monitored after three successive periods within the rumen. In parallel, we compared the behavior of permeation tubes in a water bath.

1. MATERIAL AND METHODS:

1.1. Permeation tubes: Twenty permeation tubes made of brass rods (12.5 mm × 40 mm) were loaded with about 600 to 700 mg of SF_6 at liquid nitrogen temperature (-196°C). A 6.35 mm-Swagelock nut fitted with a Teflon window (12 mm) and a stainless steel frit (2 µm) were assembled on the open end. All tubes were kept in the open air at 39°C, in an Erlenmeyer glass purged with a flow of N_2. They were then calibrated by regular weighing to the nearest tenth of a microgram (Precisa scales 92SM-202) during 6 weeks to obtain an accurate measurement of the release rate. Two groups of 12 and 8 permeation tubes, A and B respectively, were made. The average permeation rate was similar between groups; 1.720 ± 0.212 mg/d for group A and 1.676 ± 0.338 mg/d for group B. All permeation tubes had a lifetime determined to cover the entire experimental period.

1.2. Incubation environments: One cow fitted with a ruminal cannula fed a hay:concentrate diet (70:30) received the 12 permeation tubes from group A. To facilitate their recovery, tubes were tied at the end of a 1-m nylon twine with the other end fixed to the cannula. The 8 permeation tubes from group B were placed into an Erlenmeyer glass filled with water at 39°C and purged with a flow of N_2.

1.3. Incubation periods: The total experimental period lasted 6 months. After a pre-calibration period (P0) to determine the initial RR_{SF6}, permeation tubes were introduced into the rumen (group A) or in water at 39°C (group B), as described above, during 3 successive periods of 15 days (P1, P2, P3) separated by 7 weeks in the open air. After removal from the rumen or water, permeation tubes were maintained at 39°C for a week for drying. They were then calibrated for 6 weeks, in the same conditions as during the first calibration period.

1.4. Statistical Analyses: The statistical analysis on RR_{SF6} was performed using the PROC MIXED procedure of SAS for repeated measurements. Environment (rumen, water), incubation period (P0 to P3) and interaction between environment and incubation period were tested as main fixed effects. The permeation tube tested within the environment was considered as a random effect. Differences among means were tested using the Tukey–Kramer multiple comparison test and were declared significant at $P<0.05$.

2. RESULTS: The RR_{SF6} of all the permeation tubes significantly decreased between P0 and P1 *($P<0.0001$)* in the two liquid environments studied (environment × incubation period, *$P=0.24$;* figure 1). The RR_{SF6} decreased from 1.720 to 1.458 mg/day and from 1.676 to 1.512 mg/day for the permeation tubes incubated in the rumen and in water, respectively. This decrease was numerically higher for the rumen than for the water (-15 vs. -9%, respectively) but the difference was not significant. For P2 and P3, RR_{SF6} were similar and unchanged compared to P1. The RR_{SF6} averaged 1.413 and 1.404 mg/day when incubated in the rumen, and 1.501 and 1.482 when incubated in water for P2 and P3, respectively.

CONCLUSION: Our study showed that the RR_{SF6} of permeation tubes decreases after a first incubation in a liquid environment but remains stable during the second and third

incubations. These results suggest that permeation tubes should be calibrated after an initial incubation in a liquid medium, preferably in the rumen, rather than in a dry environment, as is currently proposed in the original method. Application of this pre-calibrating method should increase the accuracy of CH_4 emission measurement using the SF_6 tracer technique.

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APPENDIX:

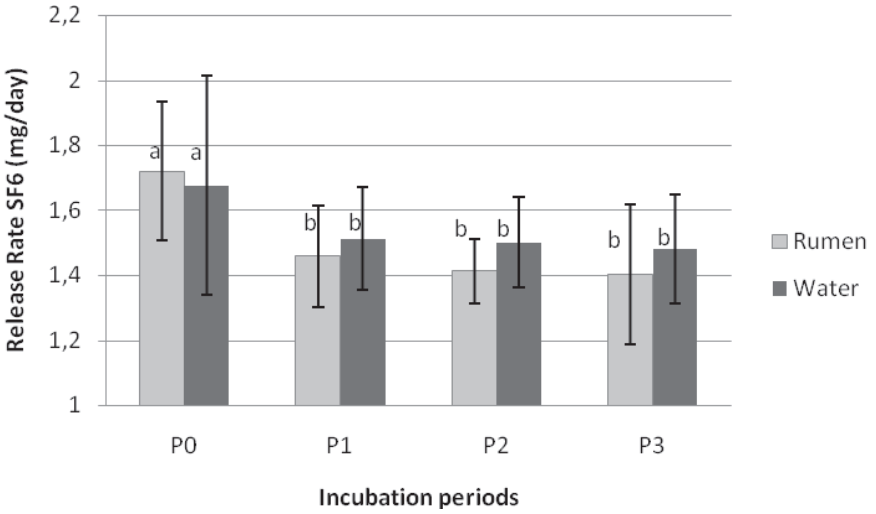

Figure 1. Release rate of SF_6 from permeation tubes incubated in the rumen or water, during 3 successive periods of 15 days (P1 to P3) separated by 7 weeks in the open air.

Means with different letters are significantly different ($P<0.05$).

TECHNIQUES FOR MEASURING VENTILATION RATE THROUGH NATURALLY VENTILATED BUILDINGS

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ABSTRACT: The objective of this work was to develop both an accurate reference measurement technique to determine ventilation rates through naturally ventilated buildings and a practical direct measuring principle for online and continuous field measurements of ventilation rates through naturally ventilated sections. Using a tracer-gas decay technique to analyse 444 laboratory experiments in a ventilated room, with a reference technique for scientific and calibration purposes, revealed a 35% inaccuracy. Aside from the assumption of perfectly mixing, a zonal modelling approach was used for post-processing of tracer-gas data and allowed a 14% inaccuracy, even at low ventilation rates. To develop a measuring sensor for continuous use on farms with natural ventilation systems, two measuring principles were tested in laboratory conditions: 1) Heat dissipation from the heat source at 17 different ventilation rates of a test room in comparison with an accurate ventilation reference measurement. This technique provided 15% inaccuracy as an average for all laboratory experiments. 2) Transit time sonic anemometers were developed for a large-scale section by using 16 acoustical lines. They were tested in a chimney with a large diameter (Φ = 0.80 m) and a length of 1.1 m. In total, 980 experiments were performed in combination with a reference technique and resulted in a 9% inaccuracy, even at disturbed flow conditions.

Keywords: measuring, ventilation rate, naturally ventilated buildings

INTRODUCTION: Almost all techniques to measure ventilation rates through naturally ventilated buildings suffer from lack of a standard and reliable reference technique to compare their accuracies. The tracer gas method is one of the most popular methods used in ventilation rate determinations in naturally ventilated buildings. The method is based on conservation of mass of an inert tracer gas injected into a building section (von Pettenkofer, 1858). The use of an artificial tracer gas, such as SF_6, is much preferred over the heat balance or CO_2 method (Phillips, et al., 2001). The tracer gas decay technique was chosen for further evaluation as a reference measurement method, as it is already widely used in the research environment, and is also used in certain practical situations. This technique provides information about global ventilation rates throughout the livestock house. While applying the tracer gas method, airflow characteristics of the ventilated space should also be considered. Therefore, this technique was further improved by incorporating it into a zonal modelling approach where distribution of tracers in space was considered.

Firstly, for field applications, an innovative measurement strategy that relies on temperature tracing of the flow field through inlet openings was largely suggested compared to the hot wire anemometer (Eren Ozcan et al., 2005). Basically, a heat source was introduced at the air opening and the ventilation rate was estimated from the rate of cooling. Secondly, a technique called “transit-time sonic anemometer” was examined and optimised at a standard test rig with a comparable scale of usual air inlet. Low ventilation rates and variable flow regimes typical to natural ventilation were reconstructed. These last two techniques were evaluated as practical tools for use in field measurements of ventilation rates through naturally ventilated buildings in the future.

1. MATERIAL AND METHODS: This study initially aims to test the tracer gas technique in laboratory test installations, which is often used as a reference method (Jiang & Chen, 2003). The tracer decay method was chosen. Drawbacks, such as fluctuations in ventilation rates and non-uniform injection of tracers at the air inlet, are minimal in well-controlled laboratory test installations.

1.1. Tracer-decay method: The method is based on the mass balance equation of the tracer gas in the air (Equation 1)

$$vol \cdot \frac{dC_i}{dt} + V \cdot C(T) = i \qquad (1)$$

where *vol* is the total volume of the ventilated space in m^3; *C* is the concentration of tracer gas in kg/m^3 at time *t*; *V* is the ventilation rate in m^3/s and *i* is the injection rate of tracer gas in kg/s inside the building volume.

In reality, gradients exist and, depending on sampling position, overall ventilation rate calculations will vary. Therefore, the accuracy of the tracer decay method was tested against a standard measuring technique (orifices) where the amount of ventilation is known with an accuracy of 6 m^3/h.

1.1.1. Laboratory test installation: The laboratory test room was a mechanically ventilated room (3.0 x 2.0 x 1.5 m). It had a slot inlet in the left sidewall just beneath the ceiling, which had a 1.24 m width and a 0.036 m height, and was positioned 1.55 m above the floor. An asymmetrically positioned, circular air outlet with a 0.16 m diameter (Φ) was located 0.21 m above the floor at a 0.31 m distance from the front wall. An enveloping chamber (4.0 x 2.5 x 3 m) was built around the test room to reduce disturbing effects. Detailed description of the test installation (Figure 1) can be found on Berckmans et al. (1993) and Janssens et al. (2004).

A mechanical ventilation system composed of a centrifugal fan and a movable cone to regulate a computer controller step motor enabled accurate measurement and control of the ventilation rate in the range of 70 - 420 m^3/h (7.6 - 46.6 air changes per hour, ACH), with an accuracy of ± 6 m^3/h. The reference technique to measure the ventilation rate is an orifice built according to the standard DIN 1952 (1982). A heat exchanger provided in the air supply duct regulated the temperature of the inflowing air from 10 to 30 °C. The heat production of different heating elements can be controlled from 0 up to 120 J/s with an accuracy of 1 J/s. To measure the three dimensional (3-D) spatio-temporal gas concentration distributions in the test chamber, 36 air sampling tubes are located in a 3-D measuring grid. The gas injection rate was controlled at a rate of 1.3 x 10^{-4} kg CO_2/s. When all the positions reached a steady tracer gas concentration, injection of CO_2 was stopped and decay rates from each position were recorded as a measure of ventilation rate at a certain point *i* in space, as well as the relative measurement error E_i in %, which represents the margin of inaccuracy by choosing different sampling positions.

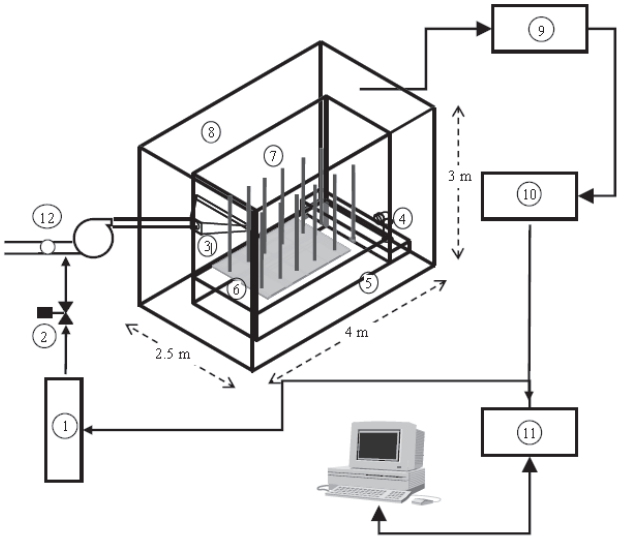

Figure 1. Laboratory test chamber with sampling system to measure spatial gas concentration distributions: (1) pressurised CO_2 gas bottle; (2) gas flow rate controller; (3) air inlet; (4) air outlet; (5) shallow water reservoir (6) aluminium conductor heat sink; (7) 3D measurement grid consisting of 36 sampling tubes; (8) envelope chamber or buffer zone; (9) multipoint sampler consisting of pc-controlled solenoid valves; (10) gas analyser; (11) data logging system; (12) orifice.

Tracer gas data were collected for six different ventilation rates (9, 13, 18, 22, 27 and 33 ACH) at the 36 positions in the sample grid and at the outlet. Each experiment with a certain ventilation rate had two repetitions. The sampling of the tracer gas at a specific sampling position lasted for one hour and twenty minutes under steady conditions. In total, 444 datasets (37 positions x 6 ACH, and 2 repetitions) were collected, which corresponds with a total experimental time of 493 hours. The sampling rate was 3.3 s.

1.2. Ventilation rate measurement based on heat dissipation: Temperature readings were used to construct an innovative prediction method for total ventilation rate estimations through naturally ventilated openings. Heat dissipated at the air inlet was used to track air flow through an inlet section. Since there is no accurate reference technique yet defined for natural ventilation in the field, a mechanically ventilated test rig (Eren Ozcan, 2011) with a standard ventilation rate measuring unit was used to test the working principle of the temperature-based method. Steady-state conditions with and without external disturbance were created at two heating levels (30 W and 50 W) in combination with 17 different ventilation rates (from 100 to 1500 m^3/h) and four different vertical disturbance levels to provide information at different flow conditions.

1.3. Ventilation rate measurement based on acoustics: Acoustical sensors, which determine the ventilation rate through a ventilation opening (Φ = 0.58 m) with a non-uniform flow pattern at low average air speeds (0 – 0.5 m/s), as in naturally ventilated buildings, were analysed. A prototype sensor was developed with 32 (2 x 16) acoustical sensors embedded into a tube with a 0.58 m diameter and 1.10 m in length. The sensors were Quantelec type, ultrasonic ceramic transducers that work with a frequency of 40

kHz. Detailed descriptions of the structure of the prototype sensor and test installation are available at Eren Ozcan (2011).

2. RESULTS AND DISCUSSION:

2.1. Tracer-decay method: The accuracy of the tracer gas technique tested highly depends on injection and sampling positions. Measurement errors up to 86% of the actual ventilation rate were observed using the decay method due to non-perfect mixing. The overall best place for tracer gas sampling was the outlet position with less than 10% measurement errors. However, in most naturally ventilated buildings the position of the outlet is often not known.

The results of the measurement errors on the ventilation rate compared with an accurate reference method (a standard orifice) are shown in Table 1.

Table 1. Comparison of relative errors in ventilation rate calculations with perfect mixing assumption and zonal model approach at different ventilation rates.

Air change rate (l/h)	Relative error (%)						
	9	13	18	22	27	33	Average
Single zone - outlet	5.1	2.3	6.0	3.9	15.3	13.1	7.6
Single zone – average	26.1	30.8	30.9	22.3	29.3	68.6	34.7
Zonal Model	19.5	14.7	20.9	1.5	16.0	8.8	13.6

The zonal modelling approach using multi-point sampling and analysis enabled the reduction of the average inaccuracy of tracer gas measurements from 35 % to 14% of the reference reading from orifices.

2.2. Heat dissipation: A more practical method for continuous use on farms with natural ventilation was tested based on velocity mapping at air inlets by the help of a heat source and temperature sensors. The physical relation between temperature difference (heat source and surrounding air) and ventilation rate was presented with validation against experimental results. Ventilation rates through openings showed an inaccuracy of 15% compared to orifice measurements, even in non-uniform flow conditions created by an external fan above the inlet opening.

2.3. Acoustics: Single and multiple acoustical measuring lines were tested at uniform and non-uniform flow patterns in the ventilation opening. From the experiments, it was concluded that 16 measuring lines gave accurate results with 9% inaccuracy at a range of 200 to 1000 m^3/h in a large (Φ = 0.58 m) chimney, even at non-uniform flow conditions (Table 2).

Table 2. Overview of the results with one and 16 measuring lines, in both directions, with and without a disturbance at the inlet at a range of 200 to 1000 m^3/h.

Method	n	Standard Error (m^3/h)	Measurement Error (%)
One line, no disturbance	80	46	12
One line, with disturbance	80	85	24
16 lines, no disturbance	30	12	7
16 lines, with disturbance	40	34	9

CONCLUSION: When using tracer gases to determine ventilation rates through naturally ventilated buildings, large variations in gas concentrations were observed inside the ventilated airspace due to non-perfect mixing (86%). Using a number of points distributed uniformly in space and calculating the amount of fresh air at each position, it was possible to reduce inaccuracy of tracer gas measurements from 35 % to 14%, on average. Therefore, tracer gas measurements can be improved by using more sampling points to assess ventilation rates through naturally ventilated buildings. The number and the position of these sampling points can be determined with a preliminary study. This method was useful as a reference method for research and calibration purposes.

As a tentative step to develop a measuring sensor for continuous use on farms with natural ventilation systems, the results of the heat dissipation study demonstrate that the temperature can be used as a means to determine ventilation rates with a 15% inaccuracy. However, robustness of the system still needs improvement through testing at various conditions and by optimising the current design.

For practical applications, the transit time acoustical measuring method offers a unique opportunity for ventilation rate measurements through naturally ventilated buildings' exhausts. Both the applicability and the 9% accuracy (disturbed flow conditions) of the transit time sonic anemometer is acceptable for field applications, which is a promising technique for further development in real-scale buildings.

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MEASUREMENTS OF METHANE USING THE LASER METHANE DETECTOR ARE RELATED TO TOTAL DAILY METHANE OUTPUT IN BEEF CATTLE

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ABSTRACT: In this experiment using beef cattle, methane (CH_4) concentration was measured using the laser methane detector (LMD) and was compared with daily CH_4 output measured using respiration chambers. Daily CH_4 outputs were measured from 68 cross-bred steers fed total mixed rations consisting of either 50:50 or 8:92 forage: concentrate (DM basis). LMD measurements were recorded independently from each steer between 09.00 and 10.00 h on each of 3 consecutive days; measurements were made every 0.5 sec during a 4 min period. The CH_4 recorded by the LMD consisted of a regular series of small respiratory peaks and larger irregular peaks representing CH_4 eructation. Daily CH_4 production (g/day, measured in respiration chambers) and CH_4 (ppm.metre) by LMD were both significantly ($P< 0.001$) lower when the cattle were fed a high concentrate diet. Significant correlations were observed between LMD CH_4 concentration and CH_4 output (g/day) measured in chambers ($P< 0.001$). Overall, CH_4 concentrations quantified with LMD were in agreement with CH_4 outputs from respiration chambers. Further validation of the LMD is needed to be able to quantify CH_4 emissions from animals under diverse management situations.

Keywords: cattle, laser methane detector, respiration chamber, diet

INTRODUCTION: Available techniques to quantify CH_4 emissions from ruminants are either expensive, time consuming, or cannot represent the animal's natural condition. The LMD is a hand-held device that measures CH_4 based on infrared-absorption spectroscopy, first used in dairy cows (Chigunda et al. 2009), which has been proposed as an alternative method to characterize enteric CH_4 emissions from animals in their natural environment. In this experiment using beef cattle, CH_4 measured using the LMD was compared with daily CH_4 output measured using respiration chambers.

1. MATERIAL AND METHODS:

1.1. Cattle and diets: Aberdeen Angus and Limousin cross-bred steers (mean live-weight 676 SD 35.1 kg) were used; the cattle were fed for at least 6 weeks before measurements with total mixed rations consisting of either 50:50 (n=36) or 8:92 (n=36) forage:concentrate (dry matter (DM) basis)

1.2. Measurements: Measurements were made over 12 weeks (6 steers / week). On day 1, steers were individually housed. On days 2 to 4, LMD measurements were recorded from each steer between 09.00 and 10.00 h. The LMD (Tokyo Gas Engineering Co. LTD) recorded CH_4 concentration (ppm.metre) every 0.5 sec with a 4 min daily measurement period and at an average of one meter distance between the LMD and the nostril area of the steer. On day 6, steers were housed in open-circuit respiration chambers and after 24 h adaptation, CH_4 concentrations in the air entering and leaving each chamber (every 6 min) and exhaust air flow (every 30 min) were measured for 48 h (days 7 and 8).

1.3. Calculations and statistical analyses:

1.3.1. Calculations: Daily CH_4 outputs from chambers were corrected to standard temperature and pressure and expressed as either g/day or g/kg DM intake (DMI).

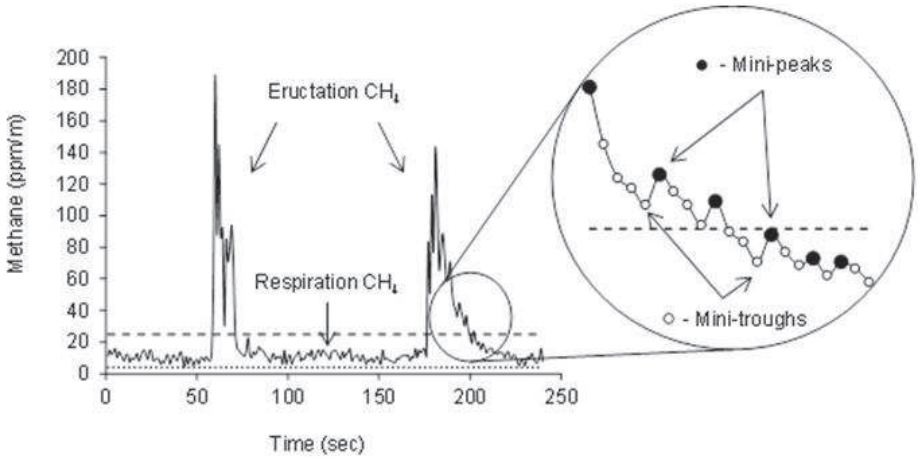

Figure 1. Analysis of Laser Methane Detector output. Dotted line represents background; dashed line represents 1 SD of the sampling period.

For each 4 min period, background CH_4 concentration was subtracted from each value. Then 1 SD of the mean of all measurements within each period was used to define measurements as either eructation (> 1 SD of the mean) or respiration (< 1 SD of the mean) CH_4 (Figure 1). Finally, data for each steer for 3 different days were combined (12 min). Since the LMD output consisted of a series of peaks and troughs (see Figure 1), mean values for all observations, all peaks, respiration peaks and eructation peaks and the sum of all CH_4 concentrations for respiration and eructation peaks for each steer were calculated.

1.3.2. Statistics: Data for 4 animals were rejected due to ill health (n=1) or a faulty chamber (n=3), leaving 34 valid observations per diet. The effects of diet were analyzed using ANOVA and agreement between measurement methods by regression analysis using general linear models (Genstat) with the number of observations in each LMD measurement period as a weighting factor.

2. RESULTS AND DISCUSSION:

2.1. Methane production: As expected, CH_4 production was significantly less ($P<0.001$) in the high concentrate than in the high forage diet, whether expressed as total output (143 SE 6.9 v 205 SE 6.1 g/day) or per kg DMI intake (13.6 SE 0.61 v 21.8 SE 0.70 g/kg DMI)

2.2. LMD: The frequency of peaks (29 to 39 /minute) was consistent with the respiration rate of cattle (Thompson et al. 2011), and peaks and troughs (Figure 1) below 1 SD of the mean of all measurements were equated with respiration. The large irregular peaks were visually related to eructation by the steers. Based only on peak values and screening, the data with a boundary of 1 SD resulted in 81 to 93% (mean 88±2.7%) of the total CH_4 (ppm.m) recorded from each animal corresponding to eructation, and the remaining 7 to 19% (mean 12±2.7%) to respiration. The number of

eructations ranged from 0 to 5 events within 4 min observation periods. The relative proportions of respiration to CH_4 eructation are consistent with other reports (Blaxter and Joyce, 1963).

In general, results were similar whether LMD CH_4 was based on all observations, all peaks, respiration peaks or eructation peaks. Therefore, the mean LMD CH_4 for all observations was used for further analyses. LMD CH_4 was greater for the high forage than the high concentrate diet ($P<0.001$). The greatest amount of variation in LMD CH_4 was explained (Figure 2) by a relationship that included diet ($P<0.001$) and DMI ($P=0.006$).

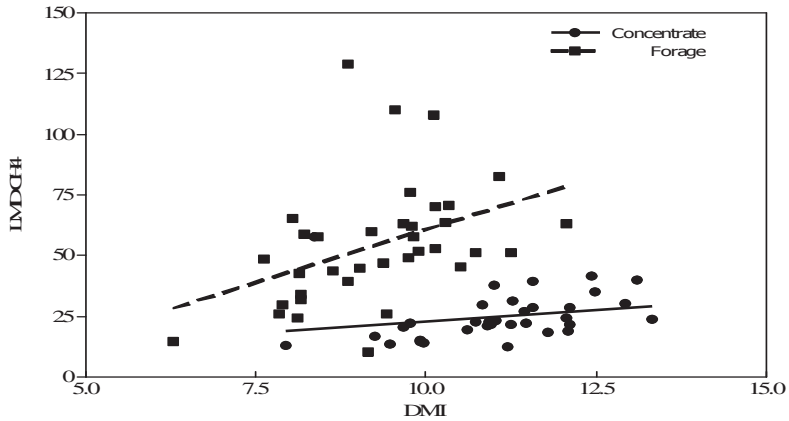

Figure 2. Relationship between LMD CH_4 (ppm.metre) and DMI (kg/day) for forage and concentrate diets.

When LMD CH_4 concentrations were compared with measured CH_4 output using respiration chambers, the relationship below was obtained (Figure 3):

LMD CH_4 (ppm.metre) = - 6.16 + 0.265 * CH_4 output (g/day, $r^2 = 0.27$, $P<0.001$).

Although this is the first report where CH_4 concentrations measured independently with the hand-held LMD are related to CH_4 output measured using respiration chambers, only a relatively small proportion of the total variance was explained. Since the relationship between measurement techniques was similar whether all data, respiration peaks or eructation peaks were used to estimate LMD CH_4, it is unlikely that bias due to the number of eructations occurring within each measurement period accounted for the low r^2. Differences between DMI between measurement periods (LMD v chamber) may explain part of the variation, as DMI during the LMD measurement explained a significant amount of variance in LMD CH_4. Similarly, although the different diets resulted, as intended, in a wide range of CH_4 outputs, different relationships between DMI and CH_4 outputs for each diet may also contribute to unexplained variance. Other known factors which will contribute to the variance are changes in LMD CH_4 in relation to time after feeding (Ricci et al. 2012) and the status of the animal (lying, standing, ruminating etc; Chagunda et al. 2011). Regardless of the above, it will be important to establish repeatability of observations over time to assess whether the LMD can be used to rank animals in terms of CH_4 output.

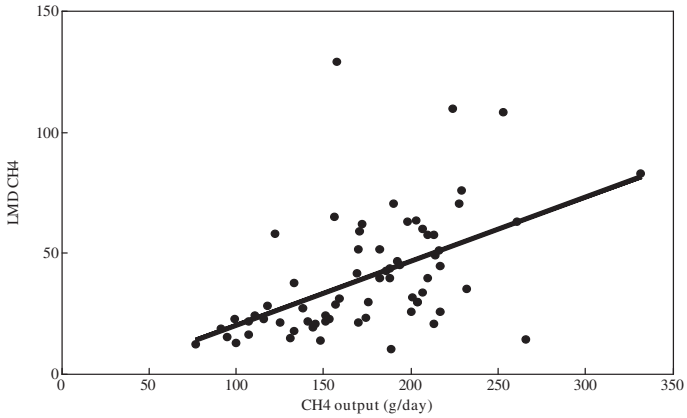

Figure 3. Relationship between LMD CH_4 (ppm metre) and daily CH_4 output (g/d).

CONCLUSION: This experiment has shown, for the first time, that independent CH_4 measurements made with the LMD are related to daily respiration chamber CH_4 outputs in cattle and; therefore, the LMD has potential as a technique for monitoring CH_4 production.

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DEVELOPMENT OF A METHOD TO PREDICT INDIVIDUAL ENTERIC METHANE EMISSIONS FROM COWS BASED ON MILK MID-INFRARED SPECTRA

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INTRODUCTION: Agriculture is directly confronted with the problem of climate change, especially concerning methane (CH_4) emissions. Indeed, livestock is considered the largest CH_4 producer from anthropogenic sources, mainly by ruminant methanogenesis. Methane contributes widely to global warming and absorbs 25 times as much infrared radiation as CO_2. In addition to those environmental concerns, the eructed CH_4 induces a significant loss (of 3- 10%) of gross energy intake for the animal. Methane emissions mainly vary with the animal (genetics, age and species), the diet (intake level, composition) and the level of milk production.
To be able to decrease CH_4 emissions from dairy cows, it is important to acquire an effective individual method to measure them that is also cheap, fast, accurate, and easily applied to a large number of cows. Based on the physiological mechanisms of ruminal digestion and lactation, it has been established that there is an indirect relationship between milk composition (including fatty acids) and the production of CH_4. Therefore, examining milk mid-infrared (MIR) spectra, which reflect milk composition, may be a way to predict enteric CH_4 emissions from individual dairy cows.

1. MATERIAL AND METHODS:

1.1. Animals and diets: Four experiments were performed on Holstein cows selected according to number of lactations. They received different diets to ensure variation in CH_4 emissions, necessary to establish a robust calibration model.

In the first experiment, 8 lactating Holstein cows were divided into two groups of four cows each. The groups had similar mean milk production (17.4 ± 3.9 kg/d). Two isoenergetic experimental diets (17 kVEM) were offered according to a 2 x 2 cross-over design. Per kg DM, diet 1 (fresh pasture) consisted of 550 g fresh-cut pasture grass (third cutting), 200 g dried beet pulp, 150 g soybean meal, and 100 g soybean hulls. Per kg DM, diet 2 (maize silage) consisted of 400 g maize silage, 200 g meadow hay, 130 g cracked maize, 150 g rapeseed meal, 55 g palm meal, 55 g soybean meal, 5 g coconut oil, and 5g flaxseed oil. Both diets contained a mixture of vitamins and minerals.

In the second experiment, 3 lactating Holstein cows with a similar mean milk production (26.2 ± 1.9 kg/d) were fed the same basal diet. Per kg DM, this diet (grass silage) consisted of 520 g grass silage, 130 g maize silage, 130 g cracked maize, 110 g soybean meal, and 110 g dried beet pulp.

The third experiment was conducted on 12 lactating Holstein cows with a similar mean milk production (25.5 ± 3.7 kg/d). Per kg DM, their total mixed ration (TMR 1) contained 140 g maize silage, 560 g grass silage, 100 g dried beet pulp, 100 g Nutex CLA, and 100 g of a concentrate mix.

Finally, in the fourth experiment 6 lactating Holstein cows with mean milk production of 26.0 ± 2.1 kg/d were fed a total mixed ration (TMR 2) consisting of 70 g straw, 200 g haylage, 350 g maize silage, and 380 g of a concentrate mix.

For all of them, the adaptation period was 21 days, and milk and CH_4 samples were then collected during 5 or 10 days. Fresh water was available at all times.

1.2. Sampling and analyses: The reference method used to measure the quantity of CH_4 eructed within 24 hours was the tracer gas sulfur hexafluoride (SF_6). A representative breath-gas sample, containing respired and eructated gas, was collected in a canister through a capillary tube kept in place between the nostril and the mouth of each animal with a halter. In the third and fourth experiments, two samples were collected each time from each animal to have a replicate. The canister was changed every 24 hours after the morning feeding. CH_4 and SF_6 concentrations were then analyzed by a gas chromatographer (Varian-Chrompack, CP-9003, Les Ulis, France) fitted with a flame ionisation detector (CH_4) and an electron-capture detector (SF_6).

In parallel, individual milk samples (50 ml) containing sodium azide were collected during each milking and analyzed with a FTIR Lactoscope spectrometer (Delta Instruments, Drachten, the Netherlands). This instrument gave the MIR spectral data as well as the direct measurement of milk components such as lactose, protein, fat, and non-protein nitrogen.

For each type of analysis (gases and milk), reference analyses were made in duplicate.

1.3. Spectral data treatment: For each test day and for each cow, one individual CH_4 measurement and two milk MIR spectra (one for each milking) were available. Therefore, the recorded spectral data were transformed to represent one daily spectrum related to one daily CH_4 record. The methodology used to create the average milk spectra (AMS) was the weighted average. It corresponds to the average of the two milk spectra of the day in proportion to the amount of milk produced by the cow in each respective milking (AM and PM). This should be the best representation of the biological background of the process.

1.4. Calibration model: The daily CH_4 measured was related to its corresponding AMS, and several equations were built using partial least squared regressions (Foss WINISI 4 software) to predict individual CH_4 emissions from the MIR spectra. A first-derivative spectral treatment was used to correct the baseline drift. The number of factors included in the equations was determined by full cross-validation (with N observations, create N models by removing N times one sample that is predicted by the other N-1), which was also used to estimate the robustness of the developed equations. Statistical parameters were also calculated to assess the accuracy of the calibration models; the calibration coefficient of determination (R^2c), the cross-validation coefficient of determination (R^2cv), the standard error of calibration (SEC), and the standard error of cross-validation (SECV). The predictability of the equations was evaluated through the ratio of performance to deviation (RPD; SD/SECV where SD was the standard deviation of the SF_6 measures). This factor should be as high as possible but values greater than 2.5 are considered satisfactory for practical and precise applications.

2. RESULTS AND DISCUSSION: Equations were built to predict the quantity of CH_4 produced per day. The best CH_4 emission prediction (L CH_4/kg milk/day) was based on 165 measurements and showed a R^2cv of 0.74 and an RPD of 1.96 (Table 1), which was promising. Indeed, this equation allows a first screening of the population: distinguish high and low CH_4 emitters. Fig. 1 shows the linear relationship between the SF_6-

measured CH_4 and the MIR-predicted CH_4 (L CH_4/kg milk). The different diets tested showed CH_4 measurements not distributed at any specific place on the line. Thus, the animal effect was greater than the feeding effect in this study. Results suggested the need to perform more measurements (especially of relatively low and high CH_4 emissions) to confirm the results obtained in this study. Moreover, external validation should be conducted by using independent SF_6 measurements of CH_4.

Table 1. Statistical parameters for the methane prediction equation.

n	R²c	R²cv	SEc	SEcv	RPD
165	0.84	0.74	3.1	3.94	1.96

SEc*:* standard error of calibration ; **SEcv**: standard error of cross validation ; **RPD**: Ratio of performance to deviation

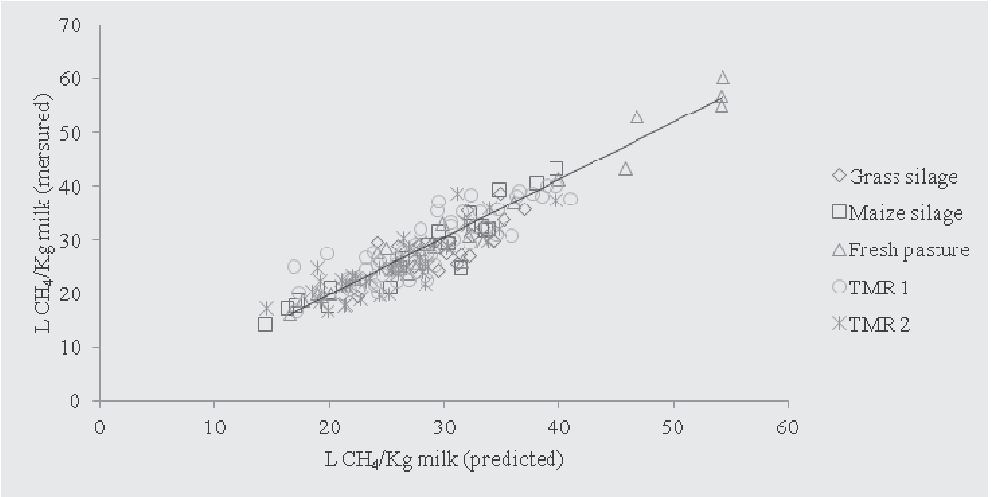

Figure 1. Relation between measured and predicted CH_4 emissions according to the type of feeding.

CONCLUSION: Results suggest a clear indirect link between CH_4 emission and milk composition assessed with MIR spectra. Therefore, prediction of enteric CH_4 emissions of individual cows seems to be feasible. Calibration results indicated that the equation could be used for screening purposes, differentiating high and low CH_4 producers. However, this equation will be refined by increasing the number of measurements to cover the range of existing CH_4 variability: genetically diverse animals from different breeds, fed on different diets and subject to diverse herd-management strategies. By applying this equation to spectral databases (e.g., related to regular milk recording), it will be possible to predict the emission of enteric CH_4 by dairy cows at small (e.g., intra-farm) and large (e.g., inter-farm, country) scales to develop management and selection tools. Through large-scale prediction of CH_4 emissions, the method could help improve knowledge about the sources of CH_4 emission variation (whether genetic or not) and about its link to other traits of interest. In this way, cows with low CH_4 emission and high milk production could be selected, and the best practices for the main production systems could be identified.

A DUAL TRACER GAS RATIO METHOD FOR THE DETERMINATION OF NH_3 EMISSIONS IN NATURALLY VENTILATED CATTLE HOUSING

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ABSTRACT: Cattle farming represents around 75% of the Swiss ammonia emissions (NH_3). The current trend emerges from naturally ventilated cattle housing systems with outdoor exercise areas, which lead to higher NH_3 emissions, mainly because of a significant increase in the soiled area. Reliable emission data for naturally ventilated systems are difficult to obtain because the air exchange rate is difficult to measure. Further, common housing systems with an outdoor exercise area include two separated areas with strongly different source intensities. A tracer ratio method with two tracer gases has been developed. In addition to the well established sulphur hexafluoride (SF_6), trifluoromethyl sulphur pentafluoride (SF_5CF_3) was introduced as a second tracer. Both tracers are continuously dosed through critical orifices. Sampling was carried out quasi-continuously by an air collecting system with critical glass orifices. The tracer gases were determined by a GC-ECD system. A photoacoustic system was used for the determination of NH_3.
The measurement concept, as well as the tracer ratio method with two tracer gases, was successfully implemented for the determination of NH_3 emissions in six naturally ventilated cattle housings. In winter, the daily average values for NH_3 across all farms varied between 6 and 23 g $LU^{-1}d^{-1}$, in the transition period between 16 and 44 g $LU^{-1}d^{-1}$ and in summer between 31 and 67 g $LU^{-1}d^{-1}$.

Keywords: ammonia emission, tracer gas ratio method, naturally ventilated cattle housing

INTRODUCTION: Ammonia (NH_3) is a relevant atmospheric pollutant. Approximately 94% of Swiss NH_3 emissions come from agriculture (2007), with 53% and 34% of these from spreading manure and animal housing, respectively (Eidgenössische Kommission für Lufthygiene 2005). Cattle accounts for 75%, i.e. the bulk of NH_3 emissions (Reidy and Menzi, 2005). Deposition of gaseous NH_3 leads to both acidification and eutrophication of the ecosystem, and NH_3 containing secondary aerosols represents a significant fraction of fine particle (PM_{10}) emissions.

In the last 20 years the distribution of dairy cattle housing systems changed significantly. Whereas in 1990, 97% of the dairy cows were kept in tie-stalls and only 3% in loose housing, the proportion of loose housing increased at least 34% (Bundesamt für Landwirtschaft, 2003 and 2010). Loose housing and outdoor exercise areas cause higher emissions because of a substantial increase in soiled areas.

The main aim of our study was to develop a dual tracer gas ratio method to determine emissions from systems that comprise two separated areas (housing and outdoor exercise area) with distinctly different source intensities, and thus to obtain NH_3 emission data from the most common dairy farming situation in Switzerland.

1. TRACER RATIO METHOD: The scientific literature describes various methods to determine emissions from naturally ventilated housing and from diffuse sources. The

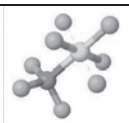
tracer gas method is especially attractive because it does not depend on a direct determination of the ventilation rate. The overall source strength is determined through the release of a tracer gas which mimics the position and relative strength of the unknown source. If both gases disperse in the same way, then the ratio of known and unknown emissions is equal to the concentration ratio of tracer and target substances and the following equation applies:

$$\dot{m}_{target} = \dot{m}_{tracer} \cdot \frac{c_{target}}{c_{tracer}}$$

where $\dot{m}$ are mass flows of target and tracer, and c is the concentration at the receptor.

Three alternatives of this concept can be distinguished: tracer decay, constant tracer concentration and constant tracer injection. Because of the high variability in ventilation conditions and given our capacity to work at low tracer concentrations (and thus low gas consumption), we chose the constant tracer injection method for our measurements. To account for two areas with possibly highly different source intensity (housing and outdoor exercise area), two tracer gases were employed. In addition to the well established SF_6 (sulphur hexafluoride), SF_5CF_3 (trifluormethyl sulphur pentafluoride) was used as a second tracer gas (Ho et al., 2008). SF_5CF_3 has a similar chemical structure and physical behavior as SF_6. In the atmosphere the concentration is about 0.1 ppt (table 1).

Table 1. Properties SF_6 and SF_5CF_3.

		
formula	SF_5CF_3	SF_6
molecular weight	196 g/mol	146 g/mol
boiling point	-20.4 °C	-63 °C
ambient conc.	~ 0.1 ppt	~ 4 ppt
atmospheric lifetime	100-1'000 y	800-3'200 y

2. MATERIAL AND METHODS: For the constant tracer injection, tracer gas standards (600-800 ppm each) were gravimetrically produced from pure substances in several dilution steps using compressed air and quantified by FTIR. In the final concentrations, the density of the tracer gases is similar to ambient air, which is essential for the assumption that NH_3 and the tracer gas propagate in the same way. Mass flow controllers (MFC) and critical orifices were used for dosing the tracer gases. The average mass flow was 6.6 and 2.9 g d^{-1} for SF_6 and SF_5CF_3, respectively. The critical orifices were fixed directly beside or on the emitting surfaces (Fig. 1). An air-collecting system consisting of Teflon (PTFE) tubes with critical glass orifices was mounted 3 m above the ground. Tracer gas concentrations were measured using a GC-ECD system which allows the simultaneous quantification of SF_6 and SF_5CF_3 with a time resolution better than 10 minutes and detection limit about 2 ppt. A commercial photoacoustic system was used to determine NH_3.

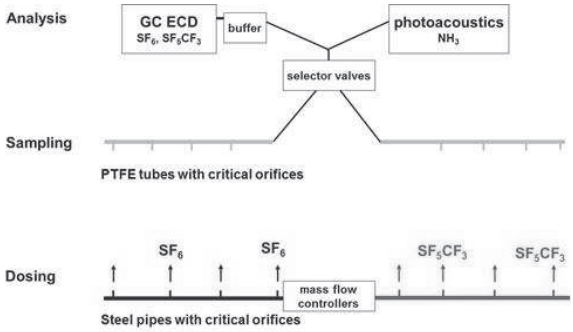


Figure 1. Measurement concept.

3. GENERAL PROCEDURE: Measurements were taken on six commercial farms with naturally ventilated cubicle loose housing systems, solid floors and an outdoor exercise area. The variation in climate over the course of the year was covered by a total of twelve measuring periods, with two out of three seasons (winter, transition period, summer) per farm. The measurements were performed on three consecutive days.

4. RESULTS AND DISCUSSION: The dual tracer method was successfully implemented for the determination of ammonia emission in naturally ventilated cattle housing. The daily average NH_3 emissions (Fig. 2) across all farms varied from 31 to 67 per livestock unit and day [g $LU^{-1}d^{-1}$] in summer, from 16 to 44 g $LU^{-1}d^{-1}$ in the transition period, and from 6 to 23 g $LU^{-1}d^{-1}$ in winter (1 LU = 500 kg live weight).

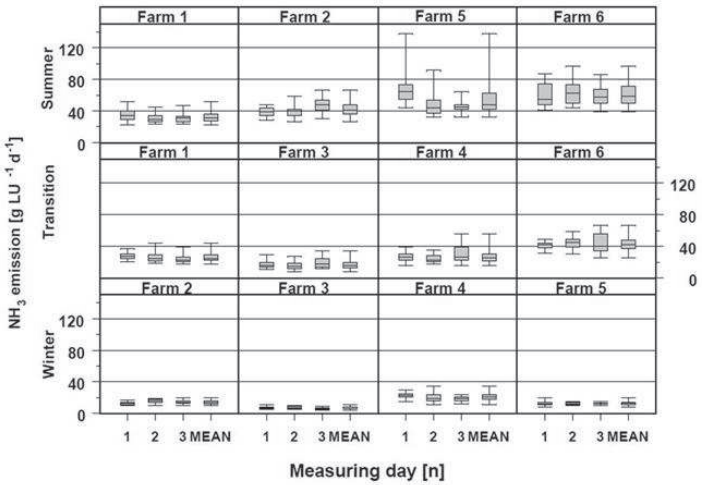


Figure 2. NH_3 emission [g LU^{-1} d^{-1}] depicted by season, measuring period and measuring day and as a mean value over three measuring days.

The daily average values show seasonal effects in ammonia levels which correlate with the outside air temperature (Fig. 2 and 3). Until outside air temperature reaches about 7°C the ammonia level stays stable. There are only farm effects in the ammonia emission.With higher outside air temperature the ammonia emissions increased with the temperature. This can be associated with NH_3 formation and release processes. More detailed results are given in Schrade et al. 2012.

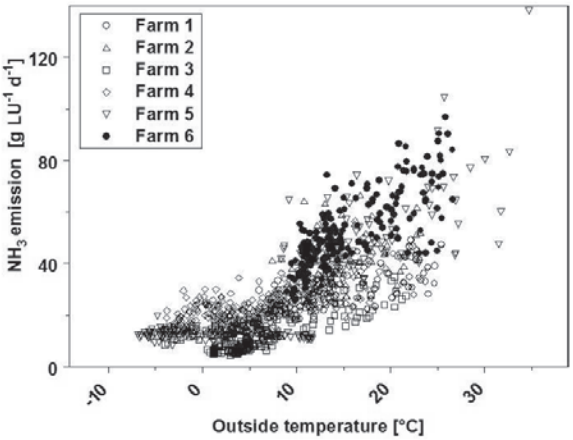


Figure 3. NH_3 emission [g LU^{-1} d^{-1}] as a function of outside air temperature [°C] coloured by different farms.

CONCLUSIONS: The measurement concept, as well as the dual tracer ratio method with SF_6 and SF_5CF_3, has proven its worth in a naturally ventilated dairy housing system with an outdoor exercise area. It was possible to demonstrate both farm and seasonal effects for NH_3 emissions by a systematic measuring approach on six commercial farms.

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Part VI.
Inventories – Environmental Evaluation

MEASURING SUSTAINABILITY IN SHEEP AND GOAT DAIRY FARMING. THE CARBON FOOTPRINT AS AN ENVIRONMENTAL INDICATOR

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ABSTRACT: Small-ruminant husbandry, like other agricultural activities, has a high impact on global climate change, especially its methane emissions from ruminant digestion and nitrous-oxide emissions from manure management and soils. The objective of this study is to give an overview of the carbon footprint of small-ruminant milk and the potential to use it as an environmental indicator in the evaluation of sustainability of sheep and goat farming. This study is largely based on a methodological approach to analyze the ecological, economic and social components of livestock systems. Measuring sustainability in animal production systems has to be equal for these three pillars of sustainability, mainly because there are interactions between them that have to be taken into account. Focusing on the environmental pillar, a set of environmental indicators has been proposed to identify impacts of farming activities on the environment and ecosystems. We work in depth with one of the more popular indicators, the "carbon footprint". This indicator can provide information not only about emissions of the production activity per ha or per unit produced (liter of milk) but also about hot spots along the supply chain. The study calculates the carbon footprint from "cradle to farm gate" in sheep farming. Preliminary results from farms in the Basque Country, Spain, show from 1.73-3.8 kg CO_2e/liter of ewe´s milk, depending on the allocation method used to divide emissions between milk and its co-products.

Keywords: small ruminants, carbon footprint, GHG, sustainability, LCA

INTRODUCTION: The FAO (2010) estimated that 18% of GHG emissions come from livestock due to the use of fossil fuels, deforestation, methane emissions from manure management and enteric fermentation, and nitrous oxide from synthetic fertilizers (Steinfeld et al., 2006). The carbon footprint summaries the greenhouse gases (GHGs) emitted from a defined system for a year. Carbon footprint takes into account all farm inputs (manufacture and transport) and processes to calculate emissions of the three most significant GHGs from agricultural activities i.e. carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). All emissions are expressed in terms of carbon dioxide equivalents (CO_2e).

1. MATERIAL AND METHODS: The carbon footprint methodology used aims to comply with PAS 2050 and Intergovernmental Panel on Climate Change (IPPC) guidelines.

1.1. Defining the system boundary: The system used in this preliminary study (Figure 1) is from cradle to farm gate. It includes emissions arising from manufacture and distribution of farm inputsm the use of energy on the farm (fuels and electricity), the GHG emissions from livestock and their excreta, and emissions from soils related to fertilizer use and manure management.

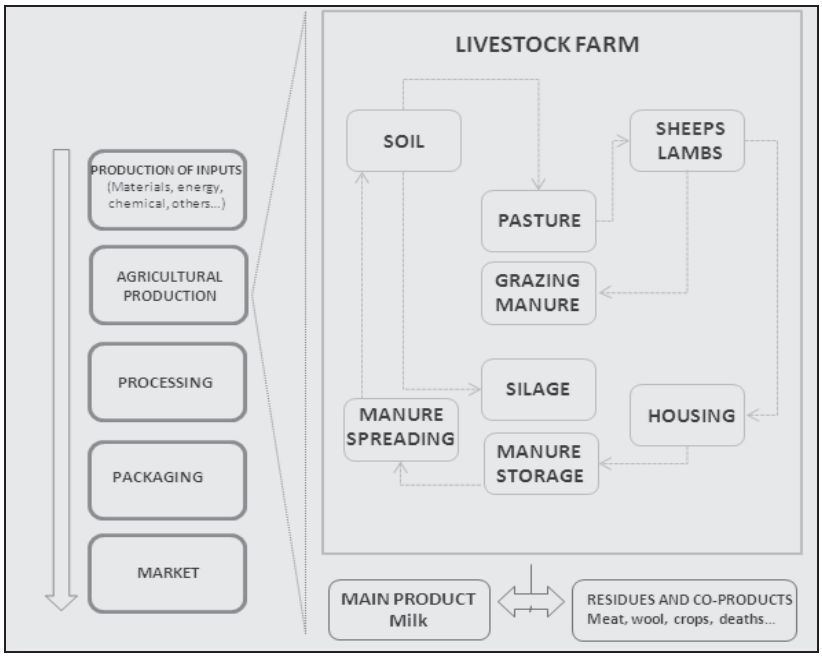

Figure 1. Definition of the system boundary.

1.2. Functional unit and allocation: The functional unit (FU) used is 1 liter of raw milk, which is useful for comparing results between farms.

Many farms produce more than one economically significant output (milk, wool, lamb meat, etc.) To assess the influence of allocation method among co-products on results, emissions from the farm were allocated using economic, mass, energy and protein allocation.

1.3. Data sources: Data for this study were taken as part of a wider farm-scale survey of economic, social and environmental indicators during 2010 at 12 sheep farms across the Basque Country, Spain. Emissions factors for farm inputs and processes were obtained from recognized standard databases (e.g., IPCC, Biograce).

2. RESULTS AND DISCUSSION: Results presented here came from one particular sheep farm, with 29.2 hectares and 352 sheep. Annual production was 49,610 litres of raw milk and 291 lambs. There was considerable variation in the estimated footprint per hectare between the farms studied.

Enteric fermentation had the highest contribution to carbon footprint in this farm (34%), followed by direct and indirect N_2O emissions (28%) (Figure 2).

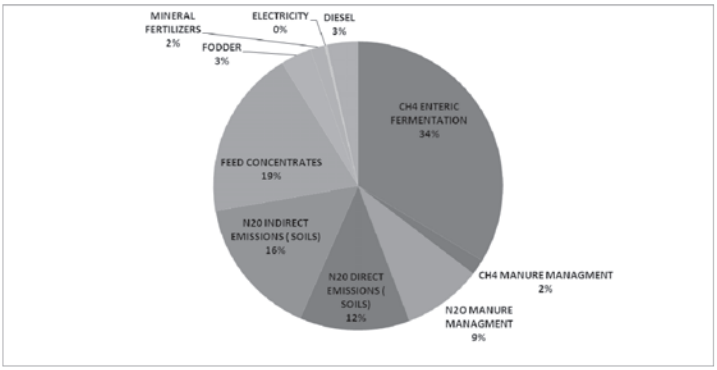

Figure 2. Sources of greenhouse-gas emissions from one sheep farm.

Table 1. Carbon footprint of sheep milk from one farm (kg CO_2e per liter of milk).

ALLOCATION METHOD	CARBON FOOTPRINT (kg CO_2 equivalent/liter of milk)
None	3.58
Economic	3.30
Mass	3.35
Energy	3.73
Protein	2.68

CONCLUSION: We quantified the carbon footprint of sheep farms according to IPPC and PAS 2050 guidelines in the Basque Country, Spain. This is preliminary research of an ongoing project. These results demonstrate the importance of enteric fermentation, manure management, use of feed concentrates, and total N applied in determining the carbon footprint of a liter of milk. Some differences were found between farm management practices. Further work is now required to validate the tool developed to calculate carbon footprints of sheep farms to compare farm results in several parts of Spain (Andalusia, Basque Country, Navarre and Castila-León). The tool will estimate the influence of management changes: reduce mineral N fertilizer applied, reduce numbers of sheep on the farm, etc., to reduce greenhouse gas emissions on farms to mitigate the environmental impact of livestock.

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ACKNOWLEDGEMENTS: This work is part of a wide multidisciplinary research project (RTA2010-00064-C04-04) that is financed by the Spanish National Institute for Agricultural and Food Research and Technology (INIA) and in which four Spanish Regions (Andalusia, Castilla & Leon, Navarra and The Basque Country) participate. The first author acknowledges the pre-doctoral financial support of INIA.

GREENHOUSE GAS EMISSIONS ON FRENCH MEAT SHEEP FARMS: ANALYSIS OVER THE PERIOD 1987-2010

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ABSTRACT: Livestock production is seen as one of the major contributors of GHG emissions. Focusing on French meat sheep breeding systems, this study sheds light on the main factors that influence resource utilization and GHG emissions. Through a sample of 1,180 farm observations, emissions were evaluated applying the Life Cycle Assessment (LCA) method. For this purpose, a large number of input categories were analyzed including feed, fertilizers, manure and services such as insurance and banking. Specificities of farming systems located in plain and mountain areas, and systems managed in conventional and organic methods are identified. The LCA results show average gross emissions of 31.6 Kg CO_2 eq for 1 Kg of carcass. When the carbon sequestration in soils is accounted for, we obtain average net emissions of 27.9 Kg CO_2 eq per CW. CH_4 represents 61% of the total emissions, CO_2 21% and N_2O 18%. On average, for each gas the main emission factor was enteric fermentation for 77% of CH_4, feed for 33% of CO_2 and manure emissions on pasture for 61% of N_2O. Organic farms' net emissions are smaller than conventional ones by 2 Kg CO_2 eq per CW. Farms located in the mountain areas also exhibit lower net emissions than those in plain areas. Finally, increasing emission trends observed over the 24 years are discussed.

Keywords: Life Cycle Assessment, greenhouse gases, heep farming

INTRODUCTION: According to IPCC (Intergovernmental Panel on Climate Change) experts, the global climate is changing, based on rapid temperature increases recorded due the release of certain gases in the atmosphere. The quick rise of the concentration of GHG is largely related to human activity (IPCC, 2007). In this paper we are concerned with livestock, as it contributes to about 18% of GHG emissions on an international scale, a higher share than transportation (Steinfeld et al., 2006). The quantification of GHGs is widely based on Life Cycle Assessment (LCA), which is a method to assess and identify sources of environmental impacts of a product or a system from "cradle to grave". The method was applied to French meat sheep farms divided into plain and mountain systems or managed in organic and conventional methods. As the LCA methodology has been largely applied to evaluate the environmental impacts of beef, there are fewer published studies regarding lamb production (Zervas and Tsiplakou, 2012). Therefore, the aim of this paper is to contribute to better knowledge of GHG emissions on lamb production farms by comparing different systems.

1. MATERIAL AND METHODS:

1.1. Data: The data came from surveys conducted by the French National Institute of Agronomic Research (INRA) over the period 1987-2010. With about 49 farms per year totalling 1,180 observations over the studied period, the areas covered are North Massif Central and its periphery. The sample is not constant because of new arrivals and retirements (average presence of 11 years).

1.2. Methodology: Life Cycle Analysis (LCA) is a technique now widely available and used in agriculture that provides clear and objective information on resource flows and environmental impacts associated with the provision of goods and services. This method requires defining the system boundary, the Functional Unit (FU), the Life Cycle Inventory and the allocation methods. The system boundary used for this LCA is defined by GHG emissions linked with lamb production from "cradle to farm gate". It includes all upstream processes (production of farm inputs and sheep farming) in livestock production up to the point where the animals or products leave the farm. Regarding the Functional Unit (FU), the studied sheep farms produce lamb and wool. Here we are only interested in the meat; therefore, the GHG emissions are expressed in Kg of CO_2 equivalents per Kg of carcass weight. As the sheep farms not only produce lamb but also wool, we allocated the environmental impacts between these two products. To do so, we resort to the commonly used mass allocation. Eventually, a collection of information on all activities included within the system boundary was necessary. The major GHG assessed are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). For methane and nitrous oxide we used the Global Warming Potentials (GWP) to convert these gases into CO_2 equivalents. The values of GWP are, respectively, 25 and 298. In this analysis we added the most commonly included emission sources (feeding, fertilizer, energy, machinery, buildings, enteric fermentation, and manure management). The principal tool for this evaluation was "Dia' terre ®" mainly developed by "ADEME" (Agency for Environment and Energy Management) and the Ministry of Food, Agriculture and Fisheries.

2. RESULTS AND DISCUSSION: Table 1 shows main results (in CO_2 equivalents per Kg of Carcass weight) of GHG emissions for each gas and carbon sequestration. In total, 26.4 Kg CO_2 eq for 1 Kg of carcass account for direct emissions and 5.2 for indirect emissions. Methane is the most significant gas and is responsible for 61% of the gross GHG. It is followed by carbon dioxide and nitrous oxide which, respectively, share 21% and 18%. Moreover, the main contributors to each gas are for CO_2 feeds (33%), fuel (20%), fertilizer (20%) and breeding purchase (18%); for CH_4 enteric fermentation (77%) and dejections (23%); for N_2O dejections in housing and pastures (61%), runoff and leaching (20%) and mineral fertilizer (17%). The results also exhibit high variability as the mean in the first quartile group stands at 24.0 and for the last quartile group it reaches 41.6. To account for the heterogeneity in our sample, the total emissions were declined for each system: mountain or plain and organic or conventional. Table 2 presents the differences among the systems and within each system, which are highly significant. We notice that farms in mountains sequester twice more than those in plain areas (mountain farms have more permanent pastures). Organic net emissions stand at 2 Kg CO_2 eq/CW below the conventional ones. A few studies used LCA to assess the number of meat sheep farms. Based on rather optimized farming systems and with another methodology (especially for soil sequestration, Leip et al., 2010) Benoit et al. (2010) obtained 27.6 Kg CO_2 eq Kg^{-1} CW of meat as gross emissions and 13.7 for net emissions. The study conducted by the French Livestock Institute (Morin et al., 2011) on three different lamb production systems exhibited gross emissions of 18.8 Kg CO_2 eq Kg^{-1} CW of meat and 15.0 for net GHG. Estimates for GHG gross emissions in other studies (Zervas and Tsiplakou, 2012) were 12.9 Kg CO_2 eq Kg^{-1} BW (Body Weight) for lamb in Wales (Edward-Jones et al., 2009), 10.0 in Ireland (Casey and Holden, 2005), 14.1 in the United Kingdom (Williams et al., 2008), and 8.6 in New Zealand (Ledgard et al., 2010). In this country, sheep farmers use fewer inputs and breeds produce more wool, supporting a larger part of the GHG emissions. However, the comparison might be biased because of the differences in the

methodology adopted by authors, system boundaries, emission factors or functional unit.

Table 1. Descriptive statistics of main results Kg CO_2 eq/CW (N=1180).

	MEAN	STANDARD DEVIATION	1ST QUARTILE	3RD QUARTILE	MIN	MAX
CO_2	6.5	2.6	5.0	7.6	1.4	26.2
CH_4	19.5	5.0	16.1	21.6	9.4	63.8
N_2O	5.6	1.7	4.4	6.6	2.1	12.5
GROSS GHG	31.6	7.3	26.5	34.9	14.9	82.4
CARBON SEQUESTRATION	3.7	3.2	1.7	5.2	-9.0	29.6
NET GHG	27.9	7.1	23.4	31.3	-7.4	62.3

Note: The negative values for carbon sequestration are due to several farms trapping carbon in the pastures and meadows instead of releasing it into the atmosphere because of tilled soils.

Table 2. Systems and emissions nature.

SYSTEMS	GROSS EMISSIONS	CARBON SEQUESTRATION	NET EMISSIONS	OBSERVATIONS
Conventional	31.6 [a]F Stat=8.730	3.6 [a]F Stat=5.430	28 [a]F Stat=9.780	1089
Organic	30.8 [b]Pr (>F)=0.000	4.8 [b]Pr (>F)=0.004	26 [b]Pr (>F) <0.0001	80
Montain	32.4 [a]F Stat=13.070	5.3 [a]F Stat=378.746	27.1 [a]F Stat=15.709	601
Plain	30.9 [b]Pr (>F)=0.000	2.1 [b]Pr (>F) <0.0001	28.8 [b]Pr (>F) <0.001	579

a refers to the Fischer statistics of the ANOVA analysis
b refers to the probability of incorrectly rejecting the null hypothesis of means equality
Note: In the sample we also have farms in conversion to organic system production, but we did not show their results because of the low number of observations.

To analyze the evolution of GHG emissions, average emissions of the total sample is declined by year. Figure 1 displays this evolution and shows upward trends, i.e. emissions increase over time. Among the factors that explain this situation is the decrease of production levels due the decline in the numerical productivity of about 18% from 1987 to 2010. We can also add the rise of the consumption of concentrate per ewe. Additionally, the higher levels of investment in machinery and breeding equipment also played a role in these observed trends. Gross and net emissions follow the same tendency. We recorded the highest emission levels in 2008. This can be explained, apart from the factors cited previously, by the apparition of a sheep disease (Bluetongue) which reduces ewe productivity. Since the Functional Unit is based on the carcass weight the relative level of GHG emissions increases.

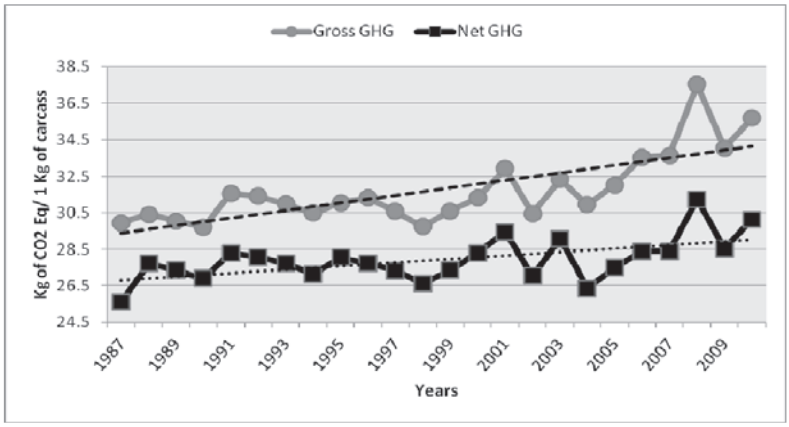

Figure 1. Gross and Net GHG emissions over years.

Note : The sample in this analysis is not constant; therefore, for the sake of comparison between years, we generate bootstrap samples for each year and compare the results to the non-bootstrap ones. We found no differences between these results and decided not to show the bootstrap results.

CONCLUSION: This work implemented a LCA on a sample of French sheep farms and concluded that the production of one Kg of carcass corresponds to the emission of about 32 Kg of CO_2 equivalents. The evolution analysis showed an increase in GHG emissions. It would be quite interesting to carry on with this work to explain the reason for the observed evolution, and to complete the study with an economic approach by looking at the correlation between these emissions and the farms' economic performances.

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VERA-VERIFICATION OF ENVIRONMENTAL TECHNOLOGIES FOR AGRICULTURAL PRODUCTION – AN INTERNATIONAL FRAMEWORK FOR TESTING AND DOCUMENTATION OF THE ENVIRONMENTAL EFFICIENCY AND OPERATIONAL STABILITY OF ENVIRONMENTAL TECHNOLOGIES

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ABSTRACT: VERA - Verification of Environmental Technologies for Agricultural Production is an international organisation for testing and verification of technologies based on specific test protocols. The VERA organisation is established in collaboration among Dutch, Danish and German environmental and agricultural authorities. The purpose of VERA is to promote the international market of environmental technologies for agricultural production by providing reliable and comparable documentation on the environmental efficiency and operational stability of environmental technologies. Test protocols were developed for 1) air cleaning technologies, 2) livestock housing and management systems, 3) covers and other mitigation technologies for reduction of gaseous emissions from stored manure, 4) measurement of gaseous emissions from land-applied manure, and 5) slurry separation technologies.

Keywords: environmental technologies, verification, gaseous emissions, methods for measuring gaseous emissions

INTRODUCTION: VERA - Verification of Environmental Technologies for Agricultural Production is an international organisation for testing and verification of technologies based on specific test protocols (www.veracert.eu). VERA was established in 2008 in collaboration among Dutch, Danish and German environmental and agricultural authorities to promote an international market for environmental technologies. The international VERA Secretariat is managed by Danish Standards Foundation on behalf of the Danish Environmental Protection Agency.

Experts from the three participating countries have developed specific VERA test protocols that comprise common standard methods for measuring the environmental efficiency and operational stability of an environmental technology. The test protocols serve as basis for providing reliable and comparable information to farmers, authorities and other stakeholders about the performance of new environmental technologies. Test protocols were developed for 1) air cleaning technologies, 2) livestock housing and management systems, 3) covers and other mitigation technologies for reduction of gaseous emissions from stored manure, 4) measurement of gaseous emissions from land-applied manure, and 5) slurry separation technologies. As emissions of ammonia, odour and dust are significant pollutant parameters in areas with intensive livestock production, the main focus of the test protocols is to test and verify the technology´s efficiency in removing these parameters. However, several other environmental parameters are included in the protocols.

VERA is organized with an International VERA Board (IVB) represented by the agricultural and environmental authorities from the three participating countries. IVB establishes rules, criteria, and scope of the activities of VERA. A number of independent technical experts from the three countries are further organised in IVC –

International Verification Committee. IVC is in charge of revising existing test protocols, developing new protocols and ensuring uniformity and reliability of test and verification activities carried out within the VERA framework. Internationally, the VERA Secretariat plays a central role in coordinating and implementing the activities IVB decides to launch and is also responsible for launching, facilitating and monitoring IVC activities.

1. VERA TEST PROTOCOLS: Basically, the test protocols are used to provide reliable and comparable information about the performance of new technologies to farmers, authorities and other stakeholders. The test protocols were developed by experts within the five technology areas mentioned above. The experts represent development and research institutions of relevance to research and development of environmental technologies for agricultural production from the three participating countries. The five VERA test protocols were developed in collaboration among experts from the three participating countries in the period from 2008 to 2009. The test protocols for air cleaning technologies and livestock housing and management systems where; however, revised and published in new versions in 2010 and 2011, respectively. The test protocols are in English and generally (the test protocols contain information about requirements for performing tests) include requirements for the test institute and the manufacturer during the test, requirements for description of the technology, length of test period and number of samples to be collected, analytical methods, statistical methods and requirements to the organisation of the test report.

A short introduction of the purpose, definitions and the contents of each of the five VERA test protocols are presented in the following:

Air Cleaning Technologies: These technologies are defined as air purifying or air treatment systems, which are connected to force-ventilated animal housing systems. The objective is to reduce emissions of ammonia, odour and dust.

Livestock Housing and Management Systems: Livestock housing and management systems that include the following: housing design including design of pen and manure storage and removal system, bedding material and other rooting materials, additional indoor technical installations and management and treatment of indoor air and indoor climate. Manure treatment, including additives and management, feed composition, including additives and management together with general management. The objective is to reduce the emissions of ammonia, odour and dust.

Covers and other Mitigation Technologies for Reduction of Gaseous Emissions from Stored Manure: In general, there is a distinction between slurry storage in tanks or lagoons and storage of solid manure in heaps or containers. The definition of environmental technologies for storage includes covers, which can reduce the contact between the stored manure and the atmospheric air, or processing of manure to reduce the gaseous emissions during storage. The objective is to reduce the emission of ammonia, odour and greenhouse gases.

Measurement of Gaseous Emissions from Land-Applied Manure: Technologies for land application of manure are defined as systems or devices that reduce the contact area between the land-applied manure and the atmospheric air, or treatments of manure that may affect emissions from land-applied manure. The central environmental pollution parameters focus on reducing the emissions of ammonia and odour.

Slurry Separation Technologies: Separation technologies are defined as technologies that separate livestock manure into one or more solid fractions and one or more liquid fractions. The efficiency of a separation technology is measured on its capability to separate phosphorus (P) and organic nitrogen (N) from the manure into the solid fraction.

Finally, the VERA organisation decided to develop a new test protocol for testing the environmental and operational performance of technologies for biogas production. The contents and purpose of this protocol has not yet been decided. France has shown great interest in participating in the development of a VERA test protocol of technologies for biogas production and the VERA organisation will thereby be extended from three to four countries. Other countries interested in participating in either the development of new test protocols or in acceptance of the contents of the already existing test protocols are welcome.

2. PROCEDURES FOR OBTAINING A VERA VERIFICATION STATEMENT:

VERA tests must be performed by independent test institutes that have the main responsibility for planning, conducting and reporting VERA test activities. The duration of the test depends on the applied VERA protocol. One year testing is necessary for air cleaning technologies and livestock housing systems, respectively, two months for technologies for land application and separation technologies and five months for storage technologies. The test report serves as the main application material. The national verification authorities verify whether the test has been performed according to the applied VERA test protocols and evaluates the environmental efficiency and operational stability of the technology based on the contents of the test report.

A VERA Verification Statement can be issued based on the national verification report. A VERA Verification Statement is issued to a specific product and therefore only accounts for the particular technology. A VERA test performed in Denmark, Germany or the Netherlands leads to the issue of a VERA Verification Statement that documents and verifies the environmental efficiency and operational stability of the tested technology. The VERA Verification Statement is the quality insurance for the performance of new environmental technology for agricultural production in Germany, The Netherlands and Denmark.

In Denmark, a VERA test is a prerequisite for acceptance of new technologies onto the Danish Environmental Protection Agency´s list of environmental technologies for agricultural production, which is a list of environmental technologies with verified environmental efficiency and operational stability. In Denmark, all five VERA test protocols are fully implemented and accepted. In the Netherlands, a VERA verification statement stating that the technology was tested according to a VERA test protocol and has environmental efficiency is accepted as valid documentation for accepting air cleaning technologies and livestock housing and management systems in the Dutch Regulation of Ammonia and Livestock list (Rav). The VERA statement ensures that no further technical evaluation is required for the national technology lists, as far as parameters concerned are covered by the statement.

3. EXAMPELS OF ONGOING VERA ACTIVITIES:

Since the initiation of the VERA system there has been an extensive focus on testing and verifying the environmental performance of air cleaning technologies. Recently, one air cleaning technology manufacturer finalised their VERA test activities. A

preliminary evaluation of the test report was performed by a group of international experts (IVC); however, the evaluation of this technology is not yet finalised. This evaluation activity is the initial step in ensuring international acceptance of VERA test results and procedures for international evaluation of tests and issuing of VERA Verification Statements.

Currently in Denmark, an extensive focus exists on introducing various technologies for acidification in livestock housing during slurry storage and during slurry land application with the purpose of reducing ammonia emissions from slurry storage and handling. The ammonia emission reduction potential from slurry acidification is being quantified by applying the VERA test on the technologies, which has increased the demand for the VERA test in Denmark. The first VERA Verification Statement issued in Denmark was to a technology acidifying slurry during land application. The VERA Verification Statement verifies that this acidification technology was tested according to the VERA Test Protocol for Measurement of Gaseous Emissions from Land-Applied Manure and that the technology has a significant ammonia emission reduction potential during land application of slurry.

CONCLUSION: VERA-verification of environmental technologies for agricultural productions is an international organisation with the participation of Germany, the Netherlands and Denmark. The five VERA test protocols describe guidelines for testing and verification of the environmental efficiency and operational stability of technologies for agricultural production. VERA tested technologies are obtained after verification of the test results according to the demands in the test protocol by an internationally accepted VERA Verification Statement. VERA ensures comparability and credibility of environmental technologies for agricultural production, which improves the international market for these technologies.

NEMA: DUTCH INVENTORY OF AMMONIA EMISSIONS FROM LIVESTOCK PRODUCTION AND FOCUS ON HOUSING AND STORAGE

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ABSTRACT: To quantify national ammonia (NH_3) emissions and to identify effective mitigation options for the Netherlands, an NH_3-inventory model NEMA (National Emission Model for Ammonia) was developed. This is an N-flow model with NH_3 emissions expressed as a percentage of total ammoniacal nitrogen (TAN) in the manure. The amount of N emitting as NH_3 from housing varied from 10% of TAN excretion for permanently housed dairy cattle to 47% for floor housing for laying hens. For manure storage outside the house, NH_3-N emissions varied from 0.3% for slurry from cattle or pigs to 8% for litter from aviaries. Total NH_3 emissions from agriculture in the Netherlands in 2009 was 88.8 Gg NH_3-N, of which 50% is from housing, 37% from manure application, 9% from mineral N fertilizer, 3% from outside manure storage, and 1% from grazing. Cattle farming was the dominant source of NH_3 emissions (49% of total), followed by pigs (24%), poultry (15%) and other animals (3%).

Keywords: NH_3, N flow model, NEMA, TAN excretion, inventory

INTRODUCTION: Agriculture is the main source of NH_3, an acidifying and eutrofying gas which has a decreasing effect on biodiversity. In the framework of the Convention on Long Range Transboundary Air Pollution (CLRTAP) and the Directive on National Emission Ceiling, countries are committed to report their national emissions. As a result, many inventory models were developed. Most models are mass flow models, as the EMEP/EEA guidebook describes (EMEP/EEA, 2009). It enables monitoring NH_3 reducing pathways throughout the manure chain and alerts on N-pollution swapping. This paper presents NEMA, an N-flow model with NH_3 emissions expressed as a percentage of total ammoniacal nitrogen (TAN) in the manure. To be able to quantify management aspects in the model, TAN is not a fixed percentage, but depends on animal category, feed composition and the N digestibility of the feed compounds. The focus of this paper is on housing and storage emissions, field emissions are presented by Huijsmans et al. (2012).

1. MATERIAL AND METHODS:

1.1. NEMA: NEMA calculates the Dutch NH_3 emissions on an annual basis as the sum of the emission from housing, manure storage outside housing, manure application to land, grazing and mineral N fertilizer (Figure 1). The emission factors (EF) are expressed as a percentage of TAN present. Because of the N-flow approach, EF's for other gaseous nitrogen compounds (nitric oxide, nitrous oxide and dinitrogen gas) are also presented.

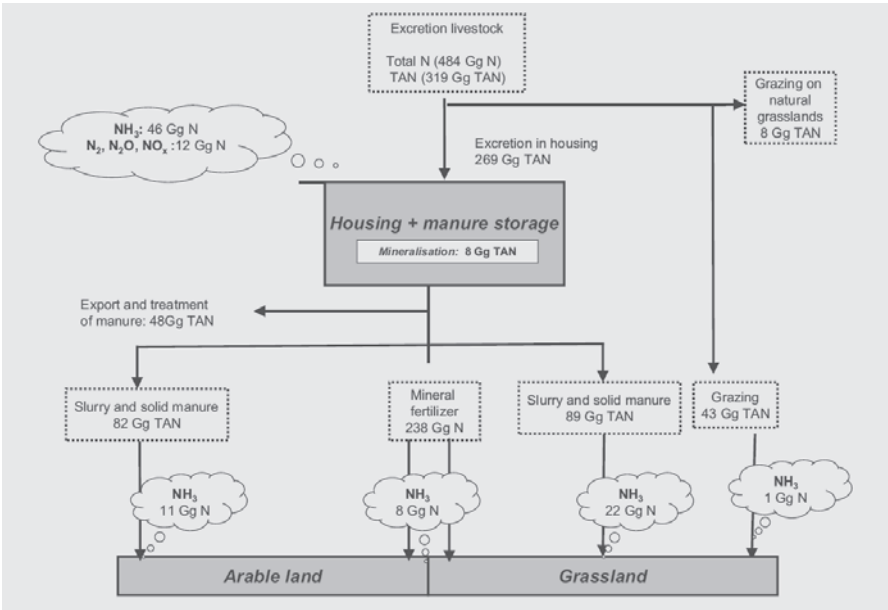

Figure 1. N-flow of NEMA, with the numbers indicating flow of N and TAN and the gaseous emissions in Gg N per year (Velthof et al., 2012).

1.2. TAN: TAN is defined as the N compounds in manure that can be easily degraded into NH_3, which consists of urine-N and for a smaller part of mineralized organic faecal N. In most N-flow models, the urine N is a fixed percentage of the total excreted N being ca. 60% of total excreted N for cattle and 70% for pig manure. Digestibility of N in the feed changes; however, because feeding compounds in the feed differ and change over time due to technical improvements of the feed (e.g. by addition of essential amino acids or enzymatic additives) and also because of market developments and pricing of feed compounds. NEMA calculates urine-N by considering the N digestibility of the compounds of the feed (Bruggen et al., 2011).

There is only a limited number of data on mineralization of organic N in manure and those available show large variation based on manure type, storage time and temperature. The NEMA model presumes a mineralization of 10% of organic N in slurry just after excretion by the animal. When the manure is solid, another process can reduce TAN: the conversion of mineral N in microbial protein-N (as opposite to mineralization). This process is called immobilization and little is quantitatively known about it. Based on the findings of Webb and Misselbrook (2004), a conservative assumption is made of a net immobilization of 25% of the excreted TAN in solid manure. However, for poultry manure, N-turnover is slower because uric acid is not as easily degradable as urea, even more when poultry manure is dried, causing low microbial activity. In the Netherlands, manure is dried in 75% of the laying hen houses. Therefore, for poultry manure net mineralization (or net immobilization) is assumed to be nil.

1.3. NH_3: Total NH_3 emission is the sum of emissions from housing, storage (mostly covered) and from the field. Field emissions are caused by the application of manure, the application of mineral N fertilizer and by grazing. Huijsmans et al. (2012)

elaborated on field emissions, this paper focuses on housing and storage. Dutch NH_3 EF's for housing (kg NH_3 y^{-1} per animal place) are recorded in a legal directive on NH_3 emission from livestock (Rav, 2009). Emissions from outside storage were deduced from measurements during pilot studies (de Bode, 1991, Oenema et al., 2000).

2. RESULTS AND DISCUSSION: Table 1 presents the N-losses relative to TAN for housing and outside storage. The Dutch national NH_3 emissions can be calculated given the EF's for housing and storage, the EF's for grazing, application and mineral N fertilizer (Huijsmans et al., 2012), the share of housing, storage systems and application techniques in the Netherlands in 2009 (Velthof et al., 2012), the number of animals and the TAN-excretion calculated based on the feed data of 2009 (Bruggen et al., 2011) (Table 2).
Total NH_3 emissions from agriculture in the Netherlands in 2009 were 88.8 Gg NH_3-N. TAN was highest in poultry and lowest in cattle manure. Housing contributed 50% of the total NH_3 emission with EF varying from 6-60% of TAN. The contribution of storage to total NH_3 emissions was only 3%, mainly because slurry storage must be covered in the Netherlands. Poultry manure storage also must be covered or are stored on the farm for a short time (ca. two weeks). The high contribution of cattle to housing emissions (40%) was partly caused by the low implementation of low-emission housing systems (5%, including tied stalls) where ca. 40% of pig houses were equipped with low emission techniques. For poultry, almost all caged systems had low emission techniques and ca. 20% of the floor housing (Velthof et al., 2012). Overall,cattle farming was the dominant NH_3 source in the Netherlands followed by, respectively, pigs, poultry and other animals (rabbits, sheep, goats, horses, mink).

Table 1. Emission factors of N-compounds relative to TAN from housing and outside storage for slurry and solid manure.

Animal category	Manure	N-losses, % of excreted TAN					
		NH_3 storage		N_2O	NO	N_2	Total
		house	outside				
Dairy							
Cows permanent housing	Slurry	10	0.4	0.15	0.15	1.5	12.2
	Solid	10	3.5	4.3	4.3	22	44.1
Female cattle < 2 years	Slurry	12	0.3	0.14	0.14	1.4	14.0
	Solid	12	3.1	3.8	3.8	19	41.7
Veal < 6 months	Slurry	26	-	0.14	0.14	1.4	27.7
Beef 6-24 months	Slurry	19	-	0.15	0.15	1.5	20.8
Sows and litters to 25 kg	Slurry	27	0.3	0.13	0.13	1.3	28.9
	Solid	27	2.6	3.7	3.7	19	56.0
Fatteners 25-110 kg	Slurry	27	0.3	0.13	0.13	1.3	28.9
Laying hens							
Battery	Dry	5.6	6.6	0.65	0.65	3.3	16.8
Floor	Litter	47	-	2.6	2.6	13	65.2
Aviary	Dry, Litter	14	7.5	2.6	2.6	13	39.7
Breeders laying hens							
Battery	Dry	6.3	7.9	0.68	0.68	3.4	19.0
Floor	Litter	60	-	2.8	2.8	14	79.6
Aviary	Dry, Litter	16	8.0	2.7	2.7	14	43.4
Broilers	Litter	22	0.9	2.9	2.9	14	42.7

Table 2. NH_3-N emissions from the Netherlands in 2009.

Animal category	TAN % of excreted N	NH_3 emission in 10^6 g N					% of excreted TAN
		Housing	Storage	Grazing	Application	Total	
Cattle	63	17.4	0.7	1.0	24.2	43.3	23
Pigs	68	15.5	0.3	0.0	5.8	21.6	28
Poultry	74	10.2	1.2	0.0	1.9	13.2	28
Other	68	1.0	0.1	0.2	1.1	2.4	19
Total Manure	-	44.1	2.3	1.2	33	80.5	25
Mineral N fert.						8.3	
Total Agricult.						88.8	

CONCLUSION: Poultry has the highest amount of TAN as % of excreted N, cattle the lowest. Poultry with floor housing has the highest NH_3-emission factor expressed as % N loss of TAN, dairy the lowest. Ammonia emission factors from slurry-based housing and storage systems are lower than from solid manure-based systems. Total NH_3 emissions from agriculture in the Netherlands in 2009 were 88.8 Gg NH_3-N, of which 50% were from housing, 37% from manure application, 9% from mineral N fertilizer, 3% from outside manure storage, and 1% from grazing. Cattle farming was the dominant source of NH_3 emissions (49% of total), followed by pigs (24%), poultry (15%) and other animals (3%).

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RECALCULATING THE GREENHOUSE GAS EMISSIONS INVENTORY FOR THE NEW ZEALAND PORK INDUSTRY

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ABSTRACT: The New Zealand (NZ) pork industry is small, producing approximately 730,000 pigs per year. Consequently, default emission factors (EF) developed by the Intergovernmental Panel on Climate Change (IPCC) have traditionally been applied to the national inventory calculations rather than EFs developed specifically for the NZ industry. This project aimed to develop NZ-specific EFs for pigs. The investigation surveyed production techniques, such as animal waste management systems (AWMS), diets, and animal finishing (kill) weights. The diets were analysed for Gross Energy (GE) and Digestible Energy (DE,%) provided to NZ pigs. IPCC equations were used to calculate enteric fermentation (EFer) emission factors, volatile solid (VS) excretion rates, while the finishing weight data was used to calculate nitrogen excretion rates (Nex).

The results of the investigation indicated that the quantity of greenhouse gas (GHG) emissions assigned to the NZ pork industry was overestimated by 59%. The reduction was largely driven by revising AWMS usage within NZ. The investigation also concluded that the GE value feed to NZ pigs was 26.9 MJ animal^{-1}day^{-1} compared to the IPCC default GE value of 37 MJ animal^{-1}day^{-1}. As a result, the emission factor for EFer and VS was revised to 1.08 kgCH_4Yr^{-1} animal^{-1} compared to 1.5 kg CH_4 Yr^{-1} animal^{-1} and 0.26 kg VS head^{-1} day^{-1} compared to 0.5kg VShead^{-1}day, respectively. The lighter animals also resulted in a lower Nex value for pigs: 10.8kg N animal^{-1} Yr^{-1} compared to 16kg N animal^{-1} Yr^{-1}.

Keywords: swine, enteric fermentation, manure management, nitrogen excretion

INTRODUCTION: New Zealand, as a signatory to the Kyoto protocol, is required to report its GHG emissions on an annual basis. For the 2008 calendar year total emissions from the agricultural sector were reported at 34,826.3 Gg $CO_{2\text{-}e}$ (46.6 % of total emissions) (MfE, 2010). Of these emissions, the pig industry was calculated to contribute approximately 190 Gg $CO_{2\text{-}e}$ or 0.5% of agricultural emissions (MfE, 2010). This small contribution is due to the industry's size when compared against the dairy, beef and sheep industries in NZ, as well as pigs being monogastric animals. Monogastric animals do not have a rumen and, as a result, they produce only small amounts of CH_4 during digestion when compared against losses in ruminant animals (Farran *et al*. 2000).

Due to its small contribution to the total GHG emission profile, the NZ pork industry has traditionally been assigned IPCC default emission factors (EFs) for a majority of the calculations used within the NZ inventory. As a result, there is a degree of uncertainty regarding emission values.The IPCC encourages countries to improve the default values used in their equations by undertaking research to obtain country specific EFs, and in 2010 the NZ Ministry of Agriculture and Forestry (MAF) and the New Zealand Pork Industry Board (NZPork) commissioned this project.

The project aimed to evaluate the EFs and IPCC equations applied to the pork industry through an on-farm analysis of operational practices, such as manure management

techniques and animal diets. From the investigation the project was able to determine NZ EFs being GE, DE%, VS and Nex that could be applied within IPCC Tier 2 methodologies to improve the accuracy of calculated emissions.

1. MATERIAL AND METHODS: Within IPCC guidelines GE, DE%, VS and Nex can be used to form the basis of all calculations on GHG emissions from enteric fermentation, manure management, as well as direct and indirect nitrous oxide (N_2O) emissions.

Over the 3-month period, farms representing approximately 70% of pig production in NZ were surveyed (56 farms). Farms consisted of a variety of production types (indoor, outdoor etc.) and pig populations (from over 3,300 sows on one site to small-scale producers with approximately 130 sows). Surveys focused on the population data for each farm (weights, average lifespan of market animals), feed information (the quantity and composition of feed consumed by animals on each farm (e.g. % of barley, maize, wheat, milk powder etc.). Feed composition was collected for all feed mixes provided on farms (e.g. creep, weaner, grower, finisher, lactating sow and dry sow meals etc.). The AWMS used on-farm (e.g. anaerobic lagoon, deep litter systems) and retention time of manure prior to land application was recorded.

All collected data was obtained down to a subclass according to age of pigs (breeding and growing) as per the 2006 IPCC inventory recommendations. Weighted averages based on population distribution per subclass were calculated to obtain EFs. All data was collated and applied to IPCC equations at a Tier 2 level. Where not specifically acknowledged, default values were applied as per the NZ 2008 GHG inventory report.

From the feed data obtained, GE and DE% for each diet was then calculated on a per animal basis using a Nutrient Matrix for NZ Feedstuff developed by Massey University (1999). GE and DE% were then applied to IPCC equations to calculate methane emissions from enteric fermentation and manure management.

Animal weights were obtained and applied to IPCC 2006 Tier 1 formulae to calculate Nex concentrations excreted from NZ pigs. The Nex value was then applied to all N_2O emissions within the inventory using IPCC guidelines.

2. RESULTS AND DISCUSSION: Overall, the results show a significant reduction (59%) in the quantity of GHG emissions released from the NZ pork industry. The reduction was largely driven by a recalculation of CH_4 emissions from the Manure Management section (See Figure 1). This sector is the largest source of emissions from the NZ pork industry, contributing 72% of the total emissions recorded in the 2008 inventory. This was predominantly due to the assumption that 55% of all pig manure is treated by anaerobic lagoons, a known hotspot of CH_4 emissions. Surveying, however, indicated that 20% anaerobic pond use in New Zealand is a more accurate estimate.

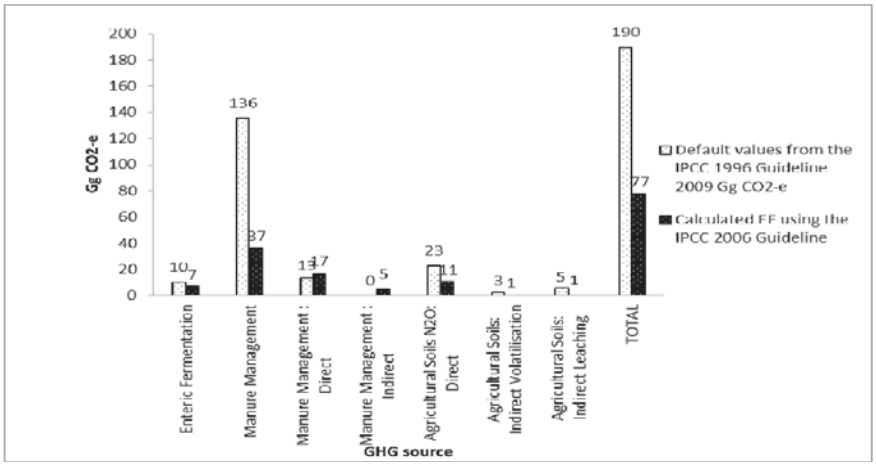

Figure 1. NZ Pork industry's GHG emissions profile.

Table 1 outlines the results found of the study for GE, EFer VS and Nex recalculated through this investigation by animal subclass. All values are a reduction on the default values provided in the IPCC 1996 guidelines. This is thought to be partially driven by the lighter weights that pigs are slaughtered in NZ (on average of 91 kg live weight, NZPork 2010, compared with an average of 123 kg live weight in the USA,USDA 2010).

Table 1. Recalculated EFs for NZ pigs.

Animal subclass	GE (MJ head^{-1} Day^{-1})	EFer (kg CH_4 head^{-1} yr^{-1})	VS (kg VS animal^{-1} yr^{-1})	Nex (kg N animal^{-1} yr^{-1})
Sows	40.14	1.58	149-165	33.7
Sows in gestation	132.46	5.21	402-453	
Boars	41.3	1.58	147-161	30.4
Suckers	4.69	0.18	11-13	0.8
Weaners	15.63	0.62	43-50	3.6
Growers	29.14	1.15	91-102.92	9.8
Finishers	39.25	1.55	129-145	15.7
Weighted averages NZ pigs	26.9	1.059	0.23-0.26	10.8
IPCC 1996	37	1.5	0.5	16

The results from this investigation show weighted average GE values, across subclasses, fed to pigs at 26.9MJhead^{-1}Day^{-1}. The GE values from this study fall within the range of energy requirements recommended for NZ pigs by National Animal Welfare Advisory Committee (2005) standards 'Animal Welfare (pigs) Code of Welfare' (2005). This, in turn, reduced the EFer value recorded in the study to 1.06 kg CH_4 head^{-1} Yr^{-1}. There is limited NZ literature calculating VS excretion from animals from each subclass of pigs. The NZ Agricultural Engineering Institute (1984) estimated 87.6 kg VS animal^{-1} Yr^{-1} for an average 50kg animal. The values from this study, however, are within the range of results reported by FSA Consulting (2007) in the Australian assessment of GHG emissions. For Nex values, the weighted average reported from our study was 10.8 kg N animal^{-1} Yr^{-1} based on the population distribution of NZ pigs. The value indicates that the current default value applied in the NZ GHGIR (i.e. 16 kg N head^{-1}yr^{-1}) may overestimate N excretion rates from NZ pigs.

CONCLUSION: The investigation demonstrated the importance of developing country-specific EFs. As a result of the investigation, the following recommendations were included into NZ's 2010 GHG inventory.

1.The recalculation of Gross Energy (GE) based on examination of animal diets in NZ (GE from 37 MJ $animal^{-1}day^{-1}$ to 26.9 MJ $animal^{-1}day^{-1}$);

2.The recalculation of enteric fermentation emissions factors from 1.5 kg CH_4Yr^{-1} $animal^{-1}$ to 1.06 kg CH_4 Yr^{-1} $animal^{-1}$;

3.The revision of excreted volatile solid (VS) from animals from 0.5VS $head^{-1}$ day^{-1} to 0.23-0.26 kg VS $head^{-1}day^{-1}$; and

4.The recalculation of nitrogen excreted from animals (Nex) from 16kg N $animal^{-1}Yr^{-1}$ to 10.8 kg N $animal^{-1}Yr^{-1}$.

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DEVELOPMENT OF A SPECIFIC SYSTEM FOR THE FRENCH INVENTORY OF AMMONIA EMISSIONS FROM LIVESTOCK MANURE MANAGEMENT: INITIAL RESULTS AND PROSPECTS

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ABSTRACT: to reflect the diversity of french livestock systems, and as a result of recent availability of data from national surveys, france has begun implementing a new inventory system based on a mass-flow approach and using a database working at regional level for 40 animal categories. This new inventory system harmonizes national data from many different sources in a microsoft access® relational database and can integrate data on animal populations, feeding, manure management and mitigation techniques' application rates. From this database, a national ammonia emissions inventory has been drawn up for the years 1990 to 2010. The results appear to be rather different from the default tier 1 methodology proposed in the emep /eea 2009 air emission inventory guidebook. Compilation of data also shows that slurry based systems are increasing, as well as alternative spreading techniques. The new inventory system tends to demonstrate that manure systems have changed over the period under study and that the implied emission factors can be rather different from the tier 1 default factors. It also shows that further statistics are needed to more accurately estimate the impact of breeding practices in the french inventories.

Keywords:inventory, ammonia, manure management, animal husbandry.

INTRODUCTION: France is an important country in terms of stock breeding and, consequently, its ammonia emissions are the highest in Europe. Most French ammonia emissions come from agriculture and nearly three quarters of these are generated by manure management (CITEPA, 2012). The pressure from supra-governmental bodies to mitigate emissions tends to increase, especially within the framework of the Gothenburg Protocol revision under the UN Geneva Convention on the Long Range Transboundary Air Pollution (CLRTP) (including Annex IX dedicated to the control of ammonia emissions from agricultural sources) and European Directives (NEC, IED). In the light of these observations, France must develop an inventory system which goes beyond a simple tier 1 calculation (in which: emission = animal number × emission factor), able to reflect the French farming practices and their changes from 1990, as well as the impacts of the future policies. Thus, to take into account these perspectives and as a result of the recent availability of data from national surveys, France has started implementing a new inventory system based on a mass-flow approach and using a database at regional level for 40 animal categories. This paper presents the establishment of this new inventory system, analyses the preliminary results obtained and proposes future improvements.

1. MATERIAL AND METHODS: To gather data and obtain feedback from national research, a Work Group on Agricultural Inventories (WG-AGRI) was set up, bringing together national agriculture experts and representatives of government bodies. This work platform enables sharing data and feedback from experience acquired on the ground, to assess choices made by CITEPA, and to increase experts' awareness of inventory issues so that they can integrate inventory needs in current/future research

projects. All the information presented in this paper has been presented to this work group.

1.1. Structure of PACRETE, the new inventory system: Accurate estimation of ammonia emissions from livestock at the regional level is a complex task which implies data compilation from many sources. The new inventory system, named PACRETE (French acronym for "Programme for the regionalized calculation of atmospheric emissions from livestock"), has been developed for the years 1990 to 2010 to estimate emissions with a maximum consistency for 40 animal categories and 22 regions. It harmonizes national data from many different sources in a Microsoft Access® relational database and integrates data on animal populations, feeding, housing, manure management, as well as all the parameters needed to estimate emissions at each stage, such as emission factors and mitigation rates.

1.1.1. EMEP/EEA 2009, a useful framework: As air pollution is a transboundary phenomenon, and as the costly mitigation measures may result in market distortion (Dämmgen et al., 2006), international regulations have been established to provide a harmonized, transparent, comparable and consistent methodology to all countries. For these reasons, the global approach of PACRETE is based on EMEP/EEA 2009 guidebooks (previous inventories were based on the tier 1 methodology from EMEP/CORINAIR 2006). However, the new French inventory goes beyond by proposing more detailed animal categories for livestock numbers, country-specific nitrogen excretion factors, and country-specific manure management data through considering mitigation measures.

1.1.2. PACRETE: model structure: NH_3 emissions are estimated using a mass-flow approach. Two fractions of N species are distinguished with respect to their ability to result in gaseous emissions: Total Ammoniacal N (TAN) and organically bound N (N_{org}). It begins with the estimate of annual N excretion and the proportion of N in the form of TAN for each class of livestock. Combined with livestock numbers, it gives the initial size of the TAN pool. Then, NH_3 is successively lost from this TAN pool at each management stage (housing/outdoors, storage, application to land), as well as emissions of N_2, NO and N_2O during storage. The mineralisation of N_{org} to TAN during slurry storage (low C/N ratio) and the immobilisation of TAN to N_{org} in the microbial biomass are also taken into account. This mass-flow system allows estimation of the consequences of reducing NH_3 emissions at one stage of manure management on emissions at later stages of manure management. For instance, storage covering can lead to an increase in emissions if inappropriate spreading techniques are used.

1.2. Animal populations from 1990: Data on animal population come from the French agricultural census, whose animal categories have changed several times since 1990. Thus, many corrections and adaptations were made to finally obtain 40 homogenous animal categories which match ones proposed in the latest agricultural census.

Table 1. Classes of animals defined in the new inventory system, and correspondence with EMEP/EEA categories.

PACRETE category	EMEP/EEA 2009	PACRETE	EMEP/EEA 2009	PACRETE	EMEP/EEA 2009	PACRETE	EMEP/EEA 2009
Dairy cows	Dairy cows	Males from dairy cattle 1 < yr < 2	"	Female kids	Goats	Hens for hatchings	Laying hens
Suckler cows	Other cattle	Males from beef cattle 1 < yr < 2	"	Goats	"	Hens for commercial egg	"
Dairy heifers for breeding > 2 yr	"	Veal calves < 1 yr	"	Other caprines	"	Pullets	"
Beef heifers for breeding > 2 yr	"	Other females < 1 yr	"	Gimmers	Sheep	Broilers	Broilers
Heifers for fattening > 2 yr	"	Other males < 1 yr	"	Dairy ewes	"	Ducks for fattening	Ducks
Males from dairy cattle > 2 yr	"	Piglets	Fattening pigs	Suckler ewes	"	Frying duckling	"
Males from beef cattle > 2 yr	"	Young pigs 20 to 50 kg	"	Other sheep	"	Turkeys	Turkeys
Dairy heifers for breeding 1 < yr <	"	Fatening pigs +50 kg	"	Saddle / Sports horse	Horses	Geese	Geese
Beef heifers for breeding 1 < yr < 2	"	Sows +50kg	Sows	Heavy draught horse	"	Guinea fowls	"
Heifers for fattening 1 < yr < 2	"	Boars +50kg	"	Mules and asses	"	Quails	"

1.3. Manure management: The study of manure management systems at regional level allows the agricultural inventory team to obtain essential data, including time spent outdoors/indoors and the allocation of manure between solid and liquid.

1.3.1. Time spent indoors and outdoors: For cattle, pigs and sheep, the time spent outdoors was estimated using housing periods provided in the 2001 and 2008 French national housing surveys. Housing periods are provided nonstop housing during the winter, from the first days of full-stabling to the first turnout to pasture. Therefore, these housing lengths were adjusted by two variables: the time spent in the dairy parlour during summer (4 hours of grazing were removed to each non-housing day to include milking length during the indoor time); the transition periods, meaning when the cows are partly outdoors during the day (calculated using data from the Observatory of dairy cow feeding (CNIEL, 2011), which provides data on housing and feeding for 15 French dairy systems). For goats, the time spent indoors and outdoors comes from the national databases PMPOA 1 and 2, which were set up by the French government to control pollution from the agricultural sector. For poultry, free-range systems were developed in France. Proportions of manure excreted on outdoor runs are provided in the national CORPEN guides (2006) for 78 fine poultry categories. Weighted values were calculated for the 10 aggregated poultry categories considered in the PACRETE system. For horses, mules and asses, the value of 5 months indoors was selected (BIOMASSE NORMANDIE, 2002).

1.3.2. Breakdown between solid and liquid manure: For cattle and pigs, excretions were allocated to solid and liquid systems using the national housing surveys conducted in 1994, 2001 and 2008. These surveys provide representative data on housing types, giving 17 different housing systems for 6 cattle categories and 19 types of floors for 6 pig categories. Correspondence tables were designed to calculate the parts of excretion deposited on liquid and solid systems. Slurry systems do not exist in France for horses, mules, asses, sheep and goats. Therefore, 100% of the excretion from these animals was allocated to straw-based systems. For poultry, most of the animals are on solid systems, except various types of duck and geese which have been allocated to slurry-based systems. For the needs of the inventory which runs from 1990, trends were considered linear between time series. For the years on either side of the first and last time series, values were considered constant.

1.4. Nitrogen excretions: For cattle, Nitrogen excretion factors (Nex) were calculated on the basis of the national CORPEN publications (1999, 2001), which enable

excretion to be adjusted according to animal size, dairy production and the different types of ingested fodder. For pigs, Nex are derived from CORPEN (2003) and are adjusted according to the progression of multiphase feeding through the period and physiological stages. For poultry, CORPEN (2006) provides excretion rates for 78 poultry categories and weighted Nex values were calculated for the 10 categories available in PACRETE. Nex for goats were derived from Schmidely et al. (2002) and Nex for horses are from Martin-Rosset et al. (2012). Given the lack of national references concerning sheep N excretion, default Nex from the IPCC's revised guidelines (1996) were used. For animals with a breeding period shorter than 1 year, breeding cycle and technical data on management were used to adapt Nex to annual average population (AAP).

1.5 Emissions factors (EFs) and mitigation measures: EFs were derived from EMEP/EEA guidebooks (2009) except for poultry in outdoors runs (Méda et al., 2012). They are expressed as a proportion of TAN. Immobilization of the TAN by the microbial biomass directly depends on the amount of straw brought to the bedding, which was estimated using correspondence tables made by national experts on the basis of experimental results. PACRETE can integrate abatement techniques at each stage of the manure management flow. Nevertheless, only a few alternative slurry spreading techniques, such as spreading with trailing hose/shoe and shallow/deep injection, could be integrated due to a significant lack of representative statistics at national level on mitigation measures. The abatement rates applied for spreading are those developed in EMEP/EEA 2009.

2. RESULTS AND DICUSSION: Table 2 shows various differences between the values used in PACRETE for the French inventory and the default ones proposed in EMEP/EEA 2009. The default Nex for dairy cows actually appears close to the 1990 level in PACRETE, which increased by 9% to reach 113.21 kg $N.AAP^{-1}.Yr^{-1}$ in 2010. This is the result of the increase in average milk yield, which reached 6,437 kg. $head^{-1}.Yr^{-1}$, compared to 4,773 kg in 1990. The most striking discrepancy concerns pigs, whose Nex are almost 40% lower in the new French inventory than in EMEP/EEA 2009 guidebooks for sows and 23% lower for fattening pigs. In the same manner, the Nex for mules and asses is overestimated by a factor of 3 when the European guidebook is used. There are also relevant differences for poultry. Excretion rates from both sources are quite close for goats, sheep and horses. Table 2 also shows that the increase of slurry systems is a pronounced trend. Although straw based systems remain the most widespread in France, slurry-based systems have increased from 37% to half the cases for dairy cattle and have doubled for suckler cows. For pigs, straw-based systems have also decreased, and now concern less than 10% of the animals. We assume these trends might inflect for sows as a result of new animal welfare regulations (EU Animal Welfare Directive). For the time spent outdoors, it is important to note the considerable differences between both sources for other cattle, goats and poultry. French goats are mainly kept inside and for poultry, free-range systems affiliated with designations of origin are more developed in France than in other European countries.Regarding ammonia emissions, Implied Emission Factors (IEF) are not significantly different from EMEP/EEA 2009 for cattle. However, IEFs are lower for pigs in the new French inventory. This difference is mainly due to the revision of the Nex, which were overestimated for the French case in the EMEP guidebook.

Table 2. Global results from the PACRETE system for the main animal categories and comparison with EMEP/EEA 2009 guidebooks.

Livestock category	Annual Average Population (AAP)	Nex	Nex (EMEP/EEA 2009)	Liquid	Solid	Time spent outdoors	Default outdoors (EMEP/EEA 2009)	IEF housing	IEF storage	IEF landspreading	IEF outdoors	IEF NH3 total	Tier 1 default IEFs (EMEP/EEA 2009) kg $NH_3.AAP^{-1}.yr^{-1}$	
		kg $N.AAP^{-1}.yr^{-1}$		%		%		kg $NH_3.AAP^{-1}.yr^{-1}$					Liquid	Solid
Dairy cows: 1990	5 303 480	104,18	105	37	63	48	51	7,7	8,02	11,99	3,62	31,32	39,3	28,7
Dairy cows	3 728 555	113,21	105	49	51	47	51	8,49	8,56	13,51	3,89	34,45	39,3	28,7
Suckler cows: 1990	3 708 150	107,06	n.p.	23	77	83	n.p.	2,6	2,82	3,88	3,87	13,17	13,4	9,2
Suckler cows	4 230 666	106,99	41	41	59	83	n.p.	2,64	2,71	4,15	3,86	13,35	13,4	9,2
Other cattle (incl. Suckler cows)	15 736 862	59,36	41	47	53	47	100	3,1	3,16	4,9	1,64	12,79	13,4	9,2
Sows: 1990	1 211 482	21,83	34,5	72	28	8	0	3,91	3,04	2,89	0,36	10,21	15,8	18,2
Sows	1 146 668	21,21	34,5	90	10	2	0	3,93	2,41	2,94	0,1	9,37	15,8	18,2
Fattening pigs: 1990	4 662 280	9,68	12	91	9	0,4	0	2,29	1,05	1,82	0,01	5,16	6,7	6,5
Fattening pigs	5 964 789	9,27	12	94	6	0,3	0	2,19	0,94	1,65	0,01	4,8	6,7	6,5
Other pigs	13 226 938	5,68	n.p.	94	6	1	n.p.	1,34	0,58	1,01	0,01	2,94	6,7	6,5
Goats	1 299 458	14,07	16	n.o.	100	11	92	1,68	0,52	0,57	0,08	2,85	n.o.	1,4
Sheep	7 956 834	16,73	16	n.o.	100	72	92	0,61	0,61	0,66	0,66	2,55	n.o.	1,4
Horses	420 392	52,56	48	n.o.	100	58	51	2,45	3,03	2,03	5,45	12,95	n.o.	14,8
Mules and asses	30 841	16,54	48	n.o.	100	58	51	0,76	0,93	0,62	1,69	4,01	n.o.	1,4
Laying Hens	67 205 000	0,67	0,77	n.o.	100	2	0	0,23	0,05	0,11	0	0,39	0,48	0,48
Broilers	121 532 000	0,44	0,36	n.o.	100	7	0	0,1	0,04	0,08	0	0,22	n.o.	0,22
Other Poultry	63 124 000	0,74	0,55-1,64	16	84	10	0	0,18	0,09	0,1	0	0,37	n.o.	0,68-0,95

n.o.: not occuring ; n.p. not provided; sources: PACRETE processing and EMEP/EEA 2009 guidebooks.

The most important emission stage is clearly manure spreading. Conversely, emissions during grazing appear rather low compared to other emission stages. For instance, grazing accounts for only 21% of the NH_3 emissions from dairy cows, though cows are kept on pasture half the year. This observation is due to low emission factors at grazing. Indeed, urine can rapidly infiltrate soil, often before urea hydrolysis is complete (WEBB et al., 2004). Thus, emissions during grazing are generally low.

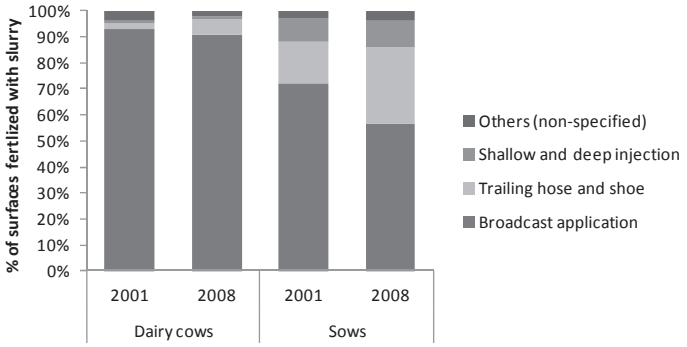

Figure 1. Land spreading techniques in France.

Table 3. Land spreading IEF for 2 animal categories on liquid systems.

100% slurry based systems (g $NH_3.AAP^{-1}.yr^{-1}$)		
Dairy cows	2001	29 337
	2008	29 565
Sows	2001	3 316
	2008	3 046

For slurry spreading, alternative techniques to broadcast application are increasing in France (figure 1). Few data are available, only for pigs and cattle for the years 2001 and 2008. Figure 1 presents an example for dairy cows and sows. It shows that shallow deep injection and trailing hose/shoe are developed and are increasingly used for slurry application on land for pigs (nearly half of the surface in 2008), whereas these techniques are still marginal for cattle. As a result, from 2001 to 2008, the land spreading IEF had decreased by 8% for pigs (Table 3) and remains rather constant for dairy cows, for which the slight decrease of broadcast application is counterbalanced by the increase of N_{ex}.

CONCLUSION AND PROSPECTS: PACRETE is a new inventory system which allows a more detailed estimation of emissions. Accurate data were compiled by region for 40 animal categories, giving a realistic and accurate description of livestock production. This system must now be improved by: making Nex more dynamic by linking them to performances and yields changes; by better estimating transfers between TAN and Norg during storage; by using country specific EFs based on national publications and research program results; and by launching surveys to follow changes in farming practices, especially for mitigation measures. Globally, compilation of statistical data shows that the lack of available statistics, especially for abatement techniques, is substantial. This leads to an overestimation of French emissions in the national inventory and an underestimation of the efforts made by the livestock sector. Indeed, biological air scrubbing, storage covering and incorporation of manure by

ploughing are still not taken into account whereas the new inventory system could integrate the related impacts. This observation stresses the need for launching new surveys to accurately estimate the abatement measures undertaken by farmers. Finally, a sensitivity analysis should be conducted to identify the variables which strongly impact the final result, which will help to prioritise the accuracy of improving these variables.

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AMMONIA EMISSIONS FROM AGRICULTURE IN SWITZERLAND: DEVELOPMENT BETWEEN 1990 AND 2010

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ABSTRACT: In 1999, ammonia (NH_3) was included as an air pollutant in the Gothenburg Protocol. Member countries of the convention must regularly report the amount of emitted NH_3 and achieve national emission ceilings. The target for Switzerland is a 13% reduction in the 1990-2010 period. Thus, the evolution of NH_3 emissions from agricultural production was investigated. Data on farm management was collected by means of surveys and emission calculations performed using the model AGRAMMON for 2002, 2007 and 2010. For 1990 and 1995, a simplified method was applied at the national scale. Total agricultural NH_3 emissions in 2010 were 47.6 kt N, of which livestock production contributed 90% (42.8 kt NH_3-N) and plant production 10% (4.8 kt NH_3-N). Total agricultural NH_3 emissions and emissions from livestock decreased by 17% and 15%, respectively, as compared to 1990. Cattle, pigs, poultry, horses/other equids and small ruminants accounted for 77%, 15%, 4%, 2% and 2%, respectively, of the emissions from livestock production and manure management. In 2010, the emission stages of grazing, housing/exercise yard, manure storage and application produced 3%, 37%, 17% and 43%, respectively, of livestock emissions. The amount of NH_3 from grazing and housing/exercise yard increased by 87% and 48%, respectively, while emissions from manure storage and application declined by 20% and 38%, respectively, since 1990. The emission reduction from livestock was mainly due to decreasing livestock numbers and more grazing, which overcompensated for the increase of emissions from grazing and housing/exercise yard**.**

Keywords: NH_3, livestock, farm and manure management, emission model, AGRAMMON

INTRODUCTION: Within the framework of the Convention on Long-range Transboundary Air Pollution and its protocols, parties must regularly report their emissions and achieve national emission ceiling values. Since 1999, ammonia (NH_3) is included as an air pollutant in the Gothenburg Protocol, covering the time period 1990 to 2010. While expert assumptions for activity data on management parameters were used for the Swiss emission inventories for 1990 and 1995, emissions from 2002 onwards were based on data from representative farm surveys. Such surveys were conducted for 2002, 2007 and 2010. This data allowed the establishment of a detailed and updated time series on emissions and provide a baseline for the negotiations on a revised protocol for the time period beyond 2010. A special objective was to study the influence of the new agricultural policy and direct payment program introduced in 1994 which includes environmental and animal welfare requirements on NH_3 emissions.

1. MATERIAL AND METHODS:

1.1. Representative farm survey for activity data: The approach chosen to collect activity data for 2010 from a representative sample of farms was basically the same as

described by Kupper et al. (2010a) for the surveys for 2002 and 2007. A twelve page questionnaire on livestock and manure management was distributed to a random sample of 6351 farms stratified according to three geographical regions (East, Central, West/South), three altitude zones (valley, hills, mountains) and five farm types. In all, 2957 questionnaires (i.e. 46.6% of the distributed questionnaires) could be included in the data analysis. The Federal Office for Statistics provided activity data on livestock numbers and farming surfaces for these farms in an anonymous form. For 2002 and 2007, the original data from Reidy et al. (2008) and Kupper et al. (2010b) could be used. More information on the farm survey is given in Kupper et al. (2010a).

1.2. Emission calculations: Emission calculations for 2002, 2007 and 2010 were individually made for each farm included in the analysis using the model AGRAMMON (Kupper et al. 2010c). AGRAMMON is a nitrogen (N) flow model that calculates emissions for grazing, housing/exercise yard, manure storage and application for 24 livestock categories. For each of the 32 classes of the survey (region x altitude x farm type), and for each livestock category, an average emission factor per animal per year for grazing, housing/exercise yard, storage and application was calculated. These mean emission factors were used for upscaling emissions to the national level by multiplying them with animal numbers of the respective classes. For the time periods between the years with calculated emissions, the NH_3 production was computed by interpolation of mean emission factors and multiplying them with animal numbers of the respective years. For 1990 and 1995, a simplified calculation at the national scale was performed. Due to the difference in the applied methodology, a full homogeneity of the emission time series cannot be assured.

2. RESULTS AND DISCUSSION:

2.1. Emissions in 2010: Total NH_3 emissions in 2010 were 51.5 kt NH_3-N, with a 92% contribution from agriculture (47.6 kt NH_3-N). Within agriculture, livestock production and manure management contributed 90% (42.8 kt NH_3-N), the rest came from mineral N fertilizers (2.0 kt NH_3-N), organic fertilizers (0.4 kt NH_3-N) and crop/grassland surfaces (2.4 kt NH_3-N). Cattle, pigs, poultry, horses/other equids and small ruminants accounted for 77%, 15%, 4%, 2% and 2%, respectively, of the emissions from livestock production and manure management.

2.2. Development of emissions between 1990 and 2010: Between 1990 and 2010, the total animal numbers of cattle and pigs both declined by 14% while the livestock categories poultry, horses/other equids and small ruminants increased by approx. 50%, 150% and 20%, respectively. Since cattle and pigs excrete the major portion of TAN from livestock (e.g. 79% and 13%, respectively, for 2010) the total amount of TAN excreted declined from 87.2 kt TAN to 76.0 kt TAN (Figure 1). Other factors, such as genetic progress and low protein feeds in pig and poultry production, supported this trend. A clear increase of animal-friendly housing systems providing more surface per head and regular outdoor exercise using exercise yards and grazing for livestock occurred in this time period. The trend was most pronounced for the prevailing livestock categories dairy cows and fattening pigs. By 2010, loose housing systems were used for 48% of dairy cows compared to an estimated portion of 5% in 1990. Housings including a multi-area pen with a littered area and an outside yard were not used for fattening pigs in the 1990s, while for 2010 the portion of animals kept in such systems reached 60%.

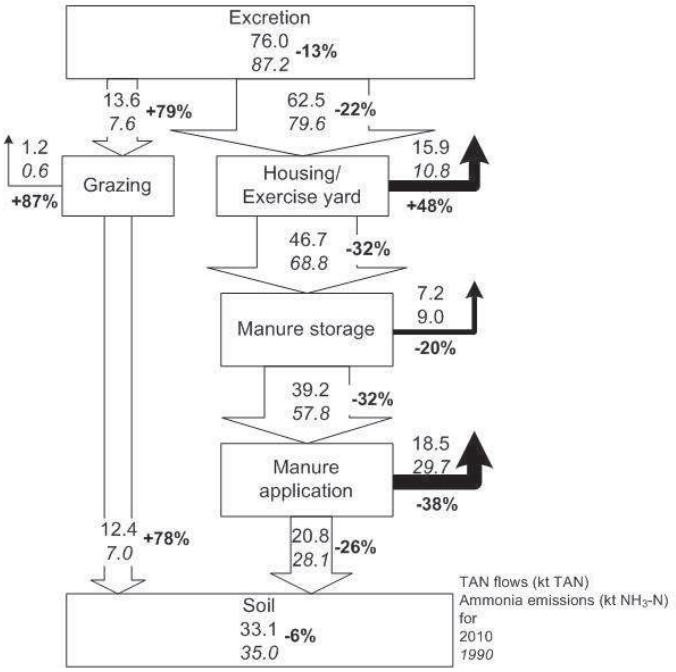

Figure 1. TAN flows (kt TAN) and ammonia emissions (kt NH_3-N) from livestock in Switzerland for 2010 (upper number) and 1990 (lower number in italics) and the difference between 1990 and 2010 in percent (%).

A share of 67% dairy cows was estimated to be grazed in 1990. This number increased to 96% up to 2010. The development of livestock management as described was similar for other livestock categories, although somewhat less pronounced. It was driven by statutory regulations aiming at improving animal welfare. The extension of grazing livestock yielded an overall increase of the TAN flow into grazing by 79% and consequently, increased emissions from pastures by 87% from 0.6 kt NH_3-N to 1.2 kt NH_3-N between 1990 and 2010. More important was the impact of grazing on the TAN flow through the cascade housing/exercise yard, manure storage and application, which was concomitantly reduced by 22%. Animal-friendly housing systems, such as loose housings for cattle and housings including a multi-area pen with a littered area and an outside yard for pigs, produce considerably more emissions than housing systems frequently used in 1990 (Ivanova-Peneva et al., 2008; Schrade et al., 2011). Therefore, the TAN flow into the stage of housing/exercise yard produced a 48% increase of emissions by 2010. The TAN flow into manure storage decreased from 68.8 kt TAN to 46.7 kt TAN. Due to a shift towards housing systems producing slurry instead of both slurry and solid manure, a 38% increase of slurry storage volume occurred between 1990 and 2010. Thus, emissions from slurry storage increased by 49% and decreased by 54% for solid manure storage. Total emissions from manure storage were 20% lower in 2010 compared to 1990. The TAN flow reaching manure application declined by 32% (1990: 57.8 kt TAN; 2010: 39.2 kt TAN). Low emission spreading technologies for slurry (mainly trailing hose) were implemented and reached a share of ca. 20% for slurry application. Emissions from manure application were 38% lower in 2010 compared to 1990. Finally, the TAN flow ending up in soil from manure application was 20.8 kt TAN in 2010, corresponding to a 26% decline since 1990. Together with the TAN remaining after grazing, a total of 33.1 kt TAN produced by livestock remained in the soil. This is slightly less than the TAN amount of 1990,

which was at 35.0 kt. Overall, the emissions from livestock and manure management declined from 50.1 kt NH_3-N to 42.8. kt NH_3-N, which corresponds to a 15% decrease between 1990 and 2010. In 2010, the emission stages of grazing, housing/exercise yard, manure storage and application produced 3%, 37%, 17% and 43%, respectively, of livestock emissions. The corresponding numbers for 1990 were 1%, 22%, 18% and 59%, respectively. Thus, emissions tended to shift from manure application to grazing and housing/exercise yard.

Emissions from plant production decreased from 7.0 kt NH_3-N to 4.8 kt NH_3-N between 1990 and 2010. This was mainly induced by the decline of mineral fertilizer use.

CONCLUSION: Ammonia emissions from livestock decreased by 15% between 1990 and 2010. The main drivers were a lower N flow due to reduced livestock numbers, more livestock grazing and progress in production technology, such as low-protein feeds and low-emission slurry spreading technologies, which compensated for higher emissions due to increasing animal-friendly housing systems.

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CO_2-EMISSIONS OF 63 LUXEMBOURG LIVESTOCK FARMS: A COMBINED ENVIRONMENTAL AND EFFICIENCY ANALYSIS APPROACH

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ABSTRACT: The specific aim of the investigation performed through the Interreg-Project OPTENERGES (www.optenerges.eu) was to evaluate both the efficiency of the production process and the environmental impact of 63 livestock farms in Luxembourg. The investigated production systems were dairy farming, beef and crop production. GHG emissions were estimated by collecting data on the farms and by applying emission factors from literature. The method used considers the net GHG emissions by subtracting carbon storage in the soil and via renewable energy from the GHG emissions resulting from production, animal farming and crop production. The investigation shows that, related to the surface, the level of CO_2 emissions for beef production (10.1 t CO_2eq/ha) are higher than emissions for dairy farming (9.1 t CO_2eq/ha) because of the higher animal density in beef systems. However, the crop production emission level is considerably lower (1.9 t CO_2eq/ha) due to carbon storage in cropland soils via minimum tillage. The product-related emissions show a 1.3 kg CO_2eq/kg average for milk, without significant differences between proteins vs. economical allocation systems. In beef production, an average emission found was 16.6 kg CO_2eq/kg live weight. Finally, in crop production the average value was 2.3 kg CO_2eq/kg produced protein. The high difference between the minima and maxima in all cases suggests that there is high potential for reducing GHG emissions among the farms.

Keywords: GHG emissions, environmental impact, efficiency analysis, livestock farming

INTRODUCTION: The investigations were performed through the Interreg IV-project "OPTENERGES" with participants from Luxembourg, Lorraine/France and Wallonia/Belgium (www.optenerges.eu). The following results illustrate GHG emissions of livestock farm members of CONVIS. CONVIS is an agricultural cooperative society giving advisory service for optimizing the use of production methods and for reducing environmental impact in agriculture. The specific aim of the investigation was to evaluate both the efficiency of the production process and the environmental impact of 63 livestock farms. The investigated production systems were dairy farming, beef and crop production.

1. MATERIAL AND METHODS: The GHG emissions are estimated by collecting data on the farms and applying emission factors from literature. The methodology was developed by CONVIS and considers the GHG emissions resulting from production, animal husbandry and plant production, and the carbon credits deriving from carbon storage in the soil and from carbon saved via renewable energy. The net GHG emissions are derived by subtracting the credits from the emissions. All results presented here refer to the net GHG Emissions. To estimate results at the system level and on farms with more than one production system, several allocation keys for the different emission sources, as well as for carbon storage, were applied. An exhaustive description of the applied method, including emission factors and allocation keys, can

be downloaded as a PDF-file from: http://www.optenerges.eu/index.php?page=5 (manuel méthodologique méthode CONVIS, on French, 32 pages)

2. RESULTS AND DISCUSSION: The investigation shows (Fig.1) that the average surface-related GHG emissions of beef production (10.1 t CO_2eq/ha) and dairy farming (9.1 t CO_2eq/ha) are higher than the GHG emissions of the entire farm. Furthermore, in comparison with these values, the GHG emission level of crop production is considerably lower (1.9 t CO_2eq/ha).

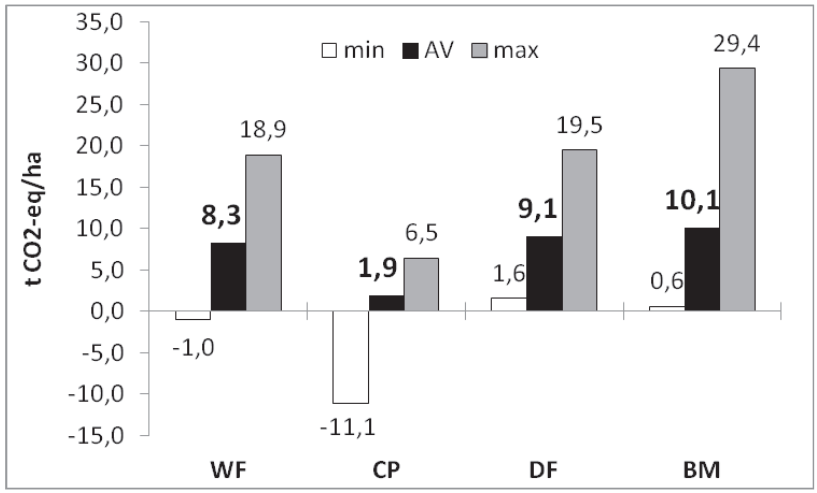

Figure 1. Minimum, average and maximum of surface-related GHG emissions of production systems in comparison with the entire farm (WF: entire farm; CP: crop production; DF: dairy farming; BM: beef meat).

An explanation for these results is furnished in Fig.2. The level of GHG emissions resulting from animal husbandry (principally CH_4 from rumen and N_2O from excreta) is highest in the beef system due to the highest level of animal density. In the crop production system, the GHG emissions deriving from animal husbandry are limited to the storage and spread of manure or slurry. Rumen emissions are completely affected by dairy farming and beef systems. The values from the entire farm can be explained by the investigated farms being livestock farms and milk as well as beef production is more significant than crop production. In comparison with dairy farming, the beef system also shows a higher level of GHG emissions originating from production. This relates to the import of sucklers for fattening on beef farms. Even when compared to the higher import of electricity, fuel, fertilizers and feedstuffs in the dairy system, the import of sucklers in the beef system exceeds these emissions. The GHG emissions in the plant production of all systems are relatively similar. Otherwise, the level of carbon credits in the investigated systems is different. In crop production, the level of stored carbon is the highest because of the common use of minimum tillage. Minimum tillage cannot be practiced at the same level in dairy farming and beef production because in these systems a large part of agricultural surface is grassland. As shown in Fig.1, there are cases in which the net GHG emissions from crop production are negative: this means that the level of carbon storage in the soil is higher than the level of GHG emissions.

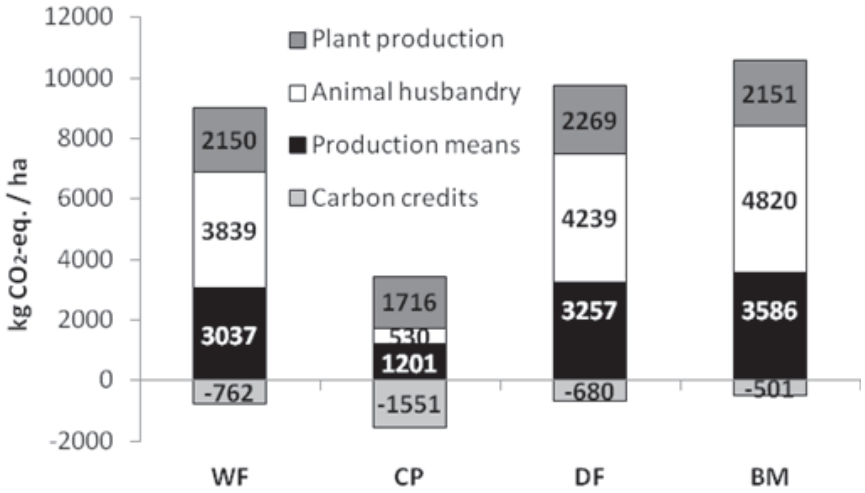

Figure 2. Composition of GHG emissions of different production systmes as well as of the entire farm (WF: entire farm; CP: crop production; DF: dairy farming; BM: beef meat).

The product-related GHG emissions (Tab.1) show a large spread between the minimum and maximum value. First, this relates to the method of accounting the emissions which also considers carbon credits. Several farms have a high level of carbon storage which allows better compensation for the GHG emissions than farms without credits. Second, the spread suggests that there is high potential for reducing GHG emissions among the farms, independent from the level of carbon storage. The average of the product-related GHG emissions presented in this paper is comparable with other investigations in the case of milk (Wetterich & Haas 1999; Béguin et al. 2009) but is higher in the case of beef (Nemecek et al. 2009; Baumgartner et al. 2009).

Table 1. Product-related GHG emissions of the investigated systems.

kg CO_2-eq	average	min	max
per kg milk	1,3	0,2	2,6
per kg beef live weight	16,6	1,4	68,8
per kg crop protein	2,3	-11,5	7,1

A final consideration concerns the relationship between production intensity and level of GHG emissions (Fig. 3). The surface-related GHG emissions show a tendency to increase with increasing level of production. Otherwise, the product-related emissions decline when production intensity increases. This indicates that the two kinds of evaluation are complementary and it is best to consider surface- and product-related GHG emissions together every time. The surface-related GHG emissions have impact on the environment; the product-related GHG emissions impact the efficiency of resource use. To avoid errors and misinterpretations, the comparison should be made between farms with a similar intensity of production. In this case, it can be expected that divergences between environmental impact and product efficiency for a homogeneous farm group are reduced to a minimum.

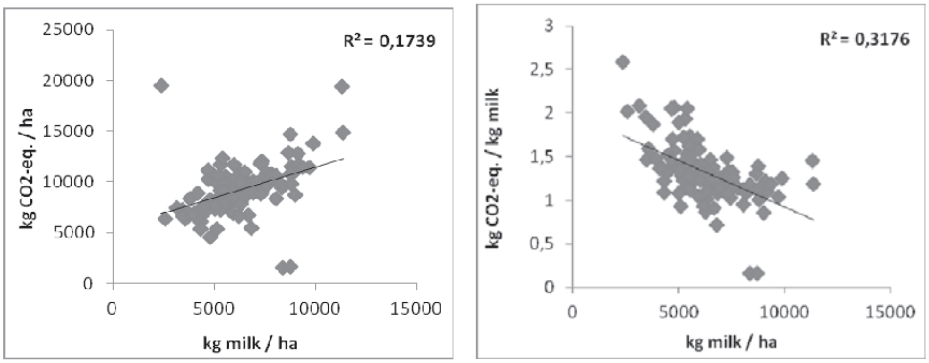

Figure 3. Relationship between production intensity and surface- (left) as well as product- (right) related GHG emissions in the case of dairy farming.

CONCLUSION: The presented analysis of GHG emissions on livestock farms clarifies that there is high potential to reduce environmental impact and to increase resource-use efficiency among farms and farm production systems.The aim for the future should be the optimization of farms and their production systems under both aspects.

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AMMONIA EMISSIONS FROM DUTCH AGRICULTURE IN 2020 ESTIMATION AND UNCERTAINTIES

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ABSTRACT: Results show that ammonia emissions from agriculture in The Netherlands amounts to 100m kg in 2020. Compared to 2007, ammonia emissions will fall by 20m kg. This drop in ammonia emissions is primarily the result of low-emission animal housing (a 10m kg decrease) and the application of animal manure (a 9m kg decrease). The estimated ammonia emissions in 2020 can differ by a range of approximately 5%. Important uncertainties are: the developing of manure processing, the number of dairy cattle, and whether or not to continue the derogation. For the goal of reducing ammonia emissions, the Netherlands Environmental Assessment Agency requires insight into ammonia emissions from agriculture in 2020. The ammonia emission depends on agricultural practices and legislation, which is reason they must be included for future developments. This study analysed: Projected ammonia emissions in 2020; Potential effects of uncertainties on ammonia emissions in 2020.
The ammonia emissions are calculated with MAMBO, a model that simulates supply and demand of manure on the Dutch manure market. The number of animals and crop acreages are derived from the LEI study by Silvis et al (2009).

Keywords: ammonia emission, prediction 2020, The Netherlands, modeling, uncertainties

INTRODUCTION: For the goal of reducing the ammonia emission, the Netherlands Environmental Assessment Agency requires insight into ammonia emissions from agriculture in 2020. The ammonia emission depends on agricultural practices, number of animals, crop acreages and legislation, which is reason they must be included in future developments. Therefore, the next questions are analysed:

What are the ammonia emissions in 2020 and what are the fundamental assumptions?

What effects do the uncertainties have for a number of relevant parameters and on the ammonia emissions in 2020?

The objective of the paper is to present a method to calculate future ammonia emissions, including the development of the agricultural structure, the technological development and relevant legislation.

1. MATERIAL AND METHODS:

1.1. Activity data: To be able to calculate ammonia emissions in 2020, assumptions should be made concerning the development of the agricultural farm structure, technological development and the amount of legislation. From a study aimed at the development of the agricultural sector (Silvis et al., 2009) the next assumptions are derived:

The lifting of the milk quota in 2015;

A 16% increase in national milk production between 2007 and 2020;

A 1.1% increase in milk production per animal per year;

The lifting of the animal permit requirement for pigs and poultry in 2015;

Usage norms from the 4th Dutch Nitrate action programme;

- The amount of manure processing.

Next, the ammonia emission reducing effects of policy and new technology are estimated and an inventory is made about the expected activity data in 2020 (Hoogeveen at al., 2010):

Low-emission housing. In 2013, at least all pig and poultry farms must have housing systems with low ammonia emissions, due to the 'housing system decision' of the Dutch government. Farms around Natura 2000 areas and farms that want to keep more animals must go even further, by needing to possess air washers. Dairy farms with newly built stables that keep the animals inside must keep them in housing systems with low ammonia emissions. With this information, experts estimate that in 2020, about one third of the pigs and poultry will be housed in stables with air washers and two thirds in housing systems with low ammonia emissions. It is expected that 30% of the cattle will be housed in housing systems with low ammonia emissions and 70% in traditional housing systems;

Grazing time of animals: With drawing on true trends, it is estimated that in 2020, 37% of dairy cattle will be kept inside the whole year;

Application techniques: The application techniques used in 2020 are based on an inventory from 2005, and changes in government rules for manure application in 2008;

Emission factors for housing and application: The emission factors from housing systems are all based on the RAV (Regeling Ammoniak en Veehouderij) and for application on Van der Hoek, 2002.

1.2. Method: At the beginning of the 1980s, LEI started with the development of the 'Manure model' (Wijnands at al., 1984). After great model revisions in 1988, 1997 and 2007 (Kruseman at al., 2008), current calculations occur with the fourth model generation (MAMBO). MAMBO can be used to calculate nutrient flows, ammonia emissions, dust and the greenhouse gases methane, dinitrogenoxide and nitrogen oxide (Luesink at al., 2007; Kruseman at al., 2008). It has recently been used in Reidy et al., 2009 to compare national ammonia (NH_3) emission models with each other. In MAMBO five key processes are included:

Manure production on farms. In this part, the ammonia emission from housing, storage and pasture at farm level are calculated as a function of the number of animals, animal types, types of feed, housing types, storage types and grazing time;

On-farm maximum allowed application of manure within statutory and farm-level constraints;
Manure excess at farm level;
Manure distribution between farms;
Application of manure resulting in soil loads with minerals. At this point in MAMBO, at municipality level, the ammonia emission from the application of manure and mineral fertilizer are calculated. The ammonia emission from application is a function of application technique, spreading time, amount of nitrogen and manure type.

2. RESULTS AND DISCUSSION:

2.1. Ammonia emissions in 2020: Ammonia emissions from agriculture are estimated at 100m kg of ammonia in 2020. This is lower than the expected policy goal of 104m kg in 2020, which is not yet certain. The majority of ammonia emissions in 2020 comes from animal manure (90%) and the remaining part (10%) from artificial fertilizers. Animal housing (54%) and application of animal manure (34%) are the major sources of ammonia emissions from manure (Table 1). Emissions from grazing and manure storage will be relatively low. Grazing animals are responsible for almost two thirds of ammonia emissions, pigs for 23% and poultry and other animals for 12% in 2020.

Table 1. Ammonia emission from animal manure in The Netherlands in 2020 in m kg of NH_3.

Source	Animal kind			
	Grazing animals	Pigs	Poultry and other	Total
Housing	28.4	11.6	6.8	46.8
Storage	0.8	0.3	3.5	4.6
Grazing	6.5	-	-	6.5
Application	22.3	8.9	0.4	31.6
Total	57.9	20.9	10.7	89.5

2.2. Changes in ammonia emissions between 2007 and 2020: Compared to 2007, ammonia emissions from animal husbandry will fall by 18% (Table 2). This drop in ammonia emissions is primarily the result of low-emission animal housing from pigs and poultry (a 10m kg decrease) and of application of animal manure (a 9m kg decrease). Due to the lower usage norms, the amount of manure that can be applied in The Netherlands decreases. In this situation it is no longer possible to apply manure from poultry, and a portion of the manure from pigs, on Dutch agriculture. This manure is processed into energy or manure products, which are exported to other countries. However, more cows are kept inside during summertime, with the effect of lower emissions from grazing and higher housing and storage emissions. Since the first of January 2012, it is forbidden to keep chickens in cages. This results in higher storage emissions from poultry.

Table 2. Changes in ammonia emission from animal manure in The Netherlands between 2007 and 2010 (2007= 100).

Source	Animal kind			
	Grazing animals	Pigs	Poultry and other	Total
Housing	104	59	68	82
Storage	114	100	121	118
Pasture	83	-	-	83
Application	94	57	31	78
Total	97	58	75	82

2.3. Uncertainties: With scenario analyses it is estimated that the ammonia emissions in 2020 can differ by a range of approximately 5%. Important uncertainties are:

When manure processing does not develop further, livestock numbers will shrink, which provides a 2.4m kg decrease in ammonia emissions;

The number of dairy cattle may increase by an extra 8%, which provides a 2.5m kg increase in ammonia emissions;

No derogation results in increased pressure on the manure market and a decrease in livestock numbers, which provides a 4.2m kg decrease in ammonia emissions.

CONCLUSIONS: Ammonia emissions from agriculture in The Netherlands are estimated at 100m kg of ammonia in 2020, and can differ by approximately 5%. Due to low emission housing from pigs and poultry and decline of the usage norms, the emissions drop to 20m kg compared to 2007.

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ARE AMMONIA EMISSIONS FROM FIELD-APPLIED SLURRY SUBSTANTIALLY OVER-ESTIMATED IN EUROPEAN EMISSION INVENTORIES

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ABSTRACT: The 2009 EMEP/EEA guidebook for agricultural emission inventories reports average ammonia (NH_3) emission factors (EF) for broad spreading by volatilisation at 55% for the applied total ammoniacal nitrogen (TAN) content for cattle slurry, and 35% losses for pig slurry, irrespective of the type of surface or slurry characteristics such as dry matter content and pH. Recent measurements show substantially lower EFs and, compared to earlier measurements, suggest a plot size dependence of the reported EF's. In this paper, we briefly review published EFs and flux measurement methods and analyse the data with the aim to disentangle possible biases caused by analytical and methodological procedures, experimental setups and management influences. Newest field experiments suggest that actual EFs would have to be reduced by a factor of two.

Keywords: ammonia emission factors, slurry application, field measurements

INTRODUCTION: The 2009 EMEP/EEA guidebook (EEA, 2009, updated June 2010) for NH_3 emission inventories indicates an average EF of 55% for cattle slurry and 35% for pig slurry for application with a splash plate, which is considered the reference case. Major measuring programs were devoted to characterise the influence of meteorological variables and of slurry composition on NH_3 volatilisation using empirical models (Sommer and Olesen, 1991; Menzi et al., 1998; Huijsmans et al., 2001). We compiled over 350 measurements from studies published between 1991 and 2011 that reported NH_3 emissions from agricultural fields after slurry application. We selected those studies for which the NH_3 emission factor (EF), defined as the cumulative NH_3 loss expressed as a percentage of the applied total ammoniacal nitrogen content (TAN) of the slurry, could be derived. The standard application technique, when the measurements started, was broad-spreading with a splash plate. Figure 1 shows an overview of the reported EF values for splash plate application used in our analysis. They range from 4% to 100 %. Different management techniques, slurry properties (e.g. pH, TAN, dry matter content: DM) and varying environmental conditions (e.g. soil properties, history of management, etc.) are responsible, to some extent, for the wide range of EF results, but potential biases in some of the used flux measurement methods may also account for a large fraction of the variability (for details see Sintermann et al., 2012).

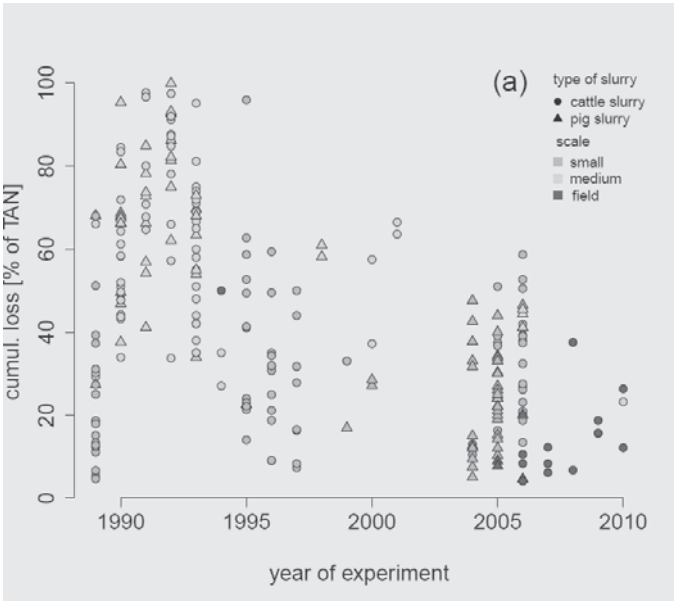

Figure 1. Reported NH_3 EFs for splash plate application plotted vs. the year of measurement.

The apparent decrease of measured EFs over the years is striking for splash plate data. Trials made before and after 2003 show a significant difference in EF ($p<0.001$). The EFs for cattle and pig slurry are not significantly different. Classifying NH_3 loss rates for all splash plate trials according to experimental scale shows significant ($p<0.001$) pair-wise differences in EFs between small scale (typically wind tunnel measurements), medium scale and field scale (> 5000m^2). Medium-size plots, generally circles between 20 and 50m, using either the Integrated Horizontal Flux approach or the ZINST method, show the highest EFs, typically between 50 and 75%. These values are considerably higher than the loss rates derived from field-scale measurements using Aerodynamic Gradient and Eddy Covariance approaches.

1. MATERIAL AND METHODS: In Switzerland, we started a new series of measurements deriving NH_3 EF's after slurry application with the goal to quantify whether the plot size has an influence on the EFs. Slurry was applied in parallel to two plots with typically 1000m^2 and 5000m^2,, respectively. NH_3 emissions in field trials are determined with the help of a dispersion model that relates a single (or multiple) concentration measurement within an emission plume to the emission rate of the corresponding (spatially limited) source area. The used backward Langrangian stochastic model (bLS) by Flesch et al. (1995, 2004) is based on particle dispersion modelling and uses Monin-Obukhov similarity theory to characterise turbulent transport. The model was implemented with a freely available software called "WindTrax" (Thunder Beach Scientific, Halifax, Canada;.com) that can be used via a graphical user interface (see review by Denmead, 2008).

2. RESULTS AND DISCUSSION: The analysis for slurry application with a splash plate (Fig.1) seems to imply that either (i) EFs for splash plate spreading have dropped substantially over the last 20 yr, or (ii) different measurement techniques provide different emission results regardless of agronomical factors. As the EFs for splash plate application over medium-size plots and determined by IHF or ZINST

were systematically elevated, the main question is whether these deviations are caused by analytical differences (e.g. determination of the NH_3 concentration), by systematic biases in the experimental setup, or by a true tendency for lower emissions over time, e.g. due to changes in slurry characteristics and/or different meteorological conditions during the experiments (or a combination of all factors). Table 1 shows the main characteristics of the two new trials devoted to investigate the potential plot-size dependence of the EFs.

Table 1: Overview on the new trials V1 and V2 (all with splash plate).

	Plot Size	Slurry Type	Application Rate	Slurry Characteristics			
				TAN	N_{tot}	DM	pH
	m^2	-	*t/ha*	*g/kg*	*g/kg*	*g/kg*	-
V1 Small Plot	10 x 10	cattle	27.8	1.07	2.00	36.7	7.3
V1 Medium Plot	30 x 30	cattle	28.0	1.07	2.00	36.7	7.3
V1 Field Scale	60 x 100	cattle	31.6	1.05	1.99	36.3	7.3
V2 Medium Plot	30 x 30	cattle	27.2	1.19	1.83	21.3	7.3
V2 Field Scale	60 x 90	cattle	28.8	1.16	1.88	15.2	7.2

The new measurements did not show any significant difference between the emissions from medium-scale plots and those determined on the field-scale typical for agricultural practice, as shown in Figure 2. These measurements also confirm EFs in the range of 15 to 30% of applied TAN - roughly half of the EF's given in the EEA handbook.

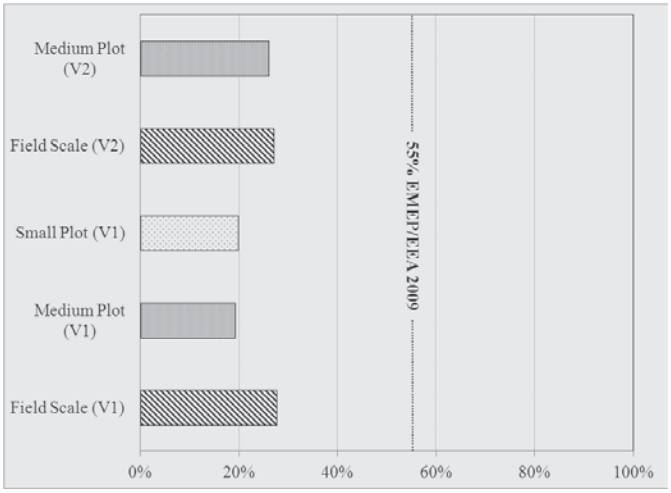

Figure 2. Emission rates (percentage of applied TAN) of the two new experiments.V1=Tänikon, V2=Posieux.

CONCLUSION: For slurry distributed by the splash-plate technique, a considerable discrepancy was found of at least a factor of 2 between EFs from earlier medium-plot/IHF measurements and recent field- scale measurements. Sintermann et al, 2012, reviewed the potential for methodological errors in the various emission measurement techniques. They found no sufficient sources of (systematic) uncertainty to explain the observed discrepancy. Newest results from Switzerland support the lower EFs and

are also in agreement with the plausibility criteria, as given by Sintermann et al., 2012.

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MODELLING THE NATIONAL CATTLE HERD TO SIMULATE MEAT AND MILK PRODUCTION AND THE GREENHOUSE GAS EMISSIONS INVENTORY

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ABSTRACT: Assessing the environmental impacts of cattle production raises the issue of handling the meat co-produced from milk production. The objective of the study was to develop a model of the national cattle herd in France that encompasses both meat and milk production and tests the effect of different technical orientations (breed, productivity and finishing type) on the direct greenhouse gas (GHG) emission inventory. The model was used to test dairy intensification (increase in Prim'Holstein milk yield), increased use of a dual-purpose breed (Normande) and beef intensification (increase in young bull and steer finishing types) under a scenario of constant milk and meat outputs. The results showed that dairy intensification slightly decreased GHG emissions when the number of calves per cow did not decrease (-2.03%). Using the Normande breed led to a slight increase in GHG emissions (+0.99%), except when veal production was replaced by beef production due to the dual purpose of this breed, which decreased GHG emissions (-4.01%). Finally, increasing the young bull finishing type led to the strongest decrease in GHG emissions (-4.66%), whereas increasing steer finishing was associated with a slight increase in GHG emissions (0.65%). This model demonstrated that inventory GHG emissions are more sensitive to the method of meat production than to dairy intensification.

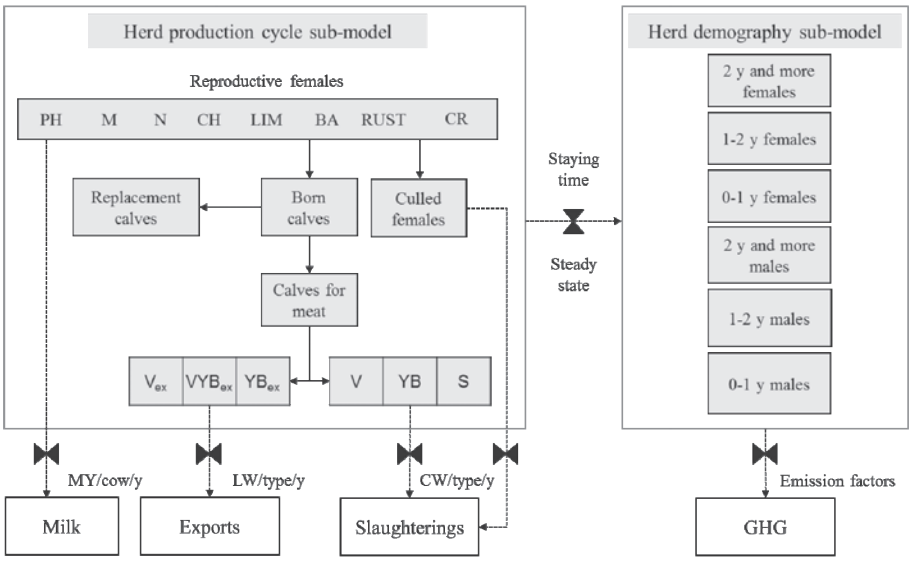
Keywords: GHG inventory, cattle, optimization, modeling, national herd

INTRODUCTION: Addressing the trade-off between the production objective and environmental impacts, especially greenhouse gas (GHG) emissions, is a major challenge for cattle farming systems. Animal intensification is often proposed as a solution. Although its efficiency has been demonstrated at the animal level, intensification results at aggregated levels are not clear. The way of handling the co-production of meat and milk by the dairy herd can modify the results of environmental evaluations (Cederberg and Stadig, 2003). Furthermore, at an aggregated level such as the country, the number of animals influences the GHG inventory. In the French context, interactions between beef and dairy herds are essential, since 35% of beef comes from the dairy herd. Our objective is to evaluate, with a model of the national cattle herd in France, the effects of different technical options on direct GHG emissions under the constraint of national production objectives. Technical options encompass the choice of breeds, their productivity and animal finishing types.

1. MATERIAL AND METHODS:

1.1. Model description: The model simulates the cattle population that satisfies constraints related to the production objective (milk and carcass weight) and national herd functioning and composition. Based on this cattle population, herd demography is simulated to compute the GHG inventory.

1.1.1. Herd production cycle sub-model: This sub-model (Figure 1) integrates 8 breeds of reproductive females that generate culled cows and calves, depending on parameters specified for each breed (numerical productivity, calf and adult mortalities, crossing rate and sex-ratio). Calves not kept for replacement are dedicated to meat production and diverted among different finishing types depending on a repartition matrix. They can be slaughtered as veal (V), young bull (YB) or steer (S) or exported alive as veal (V_{ex}), very young bull (VYB_{ex}) or young bull (YB_{ex}). The numbers of animals within each category (finishing type, culled or reproductive females) are combined with productivity parameters to compute national productions (milk, slaughtering and exports).



BA: Blonde d'Aquitaine; CH: Charolaise; CR: cross-breed; CW: carcass weight; LIM: Limousine; LW: live weight; M: Montbéliarde; MY: milk yield; N: Normande; PH: Prim'Holstein; RUST: Aubrac and Salers; S: steer; V: veal; V_{ex}: veal exported; VYB_{ex}: very young bull exported; YB: young bull; YB_{ex}: young bull exported

Figure 1. General description of the national cattle herd model.

1.1.2. Herd demography sub-mode: This sub-model simulates herd demography and GHG emissions based on the numbers of animals simulated by the herd production cycle sub-model (Figure 1). To compute the demography simply, we assumed a steady-state herd, which means that annual production remains constant over the years. To calculate the number of animals in each age class, the number of calves kept for replacement is combined with age at first calving, and the numbers of animals in each finishing type are combined with age at slaughter or export. Each age class is associated with an emission factor accounting for enteric CH_4 (adjusted for milk production with the equation of Vermorel et al., 2008) and CH_4 and N_2O related to manure management (CITEPA, 2012).

1.2. Simulations: The model is implemented with the GAMS software to perform optimization under constraints. Depending on the production objectives (milk, slaughterings and exports) and the input parameters specified for each scenario (herd functioning, productivity and staying time), the model predicts the number of reproductive females for each breed that satisfy constraints, the associated cattle population and the GHG emissions. Three contrasting intensification scenarios were

simulated (Table 1): i) dairy-herd intensification; ii) use of a dual-purpose breed and iii) beef-herd intensification. Simulations were performed with the same national production objectives (milk, slaughterings and exports) with a 1% tolerance. The reference scenario corresponds to the French situation in 2010.

Table 1. Model parameterization for the 6 scenarios simulated with the national cattle herd model, reflecting three types of intensification.

	REF	DI+	DI-	N100	N100V-	YB+	S+
Type of intensification	Reference	Dairy intensification		Dual-purpose breed		Beef intensification	
PH milk yield	7500	11500	11500	7500	7500	7500	7500
PH numerical productivity[1]	0.93	0.93	0.75	0.93	0.93	0.93	0.93
% N cows in the dairy herd	12	12	12	100	100	12	12
% N calves finished as veal (pure - cross-bred)	45 - 28	45 - 28	45 - 28	45 - 28	0 - 0	45 - 28	45 - 28
% of beef calves finished as YB	< 50	< 50	< 50	< 50	< 50	> 75	< 50
% of beef calves finished as S	< 50	< 50	< 50	< 50	< 50	< 50	> 70

[1] number of calves per cow; PH: Prim'Hosltein breed; N: Normande breed; YB: young bull; S: steer

2. RESULTS AND DISCUSSION:

2.1. Results: All simulations led to an optimal solution. The model found a cattle population that satisfied all herd constraints and French 2010 production objectives for milk (23.8×10^6 T) and for meat (1809×10^3 T of carcass equivalent, with 600×10^3 due to 1.44 M head exported alive). Scenario predictions (Table 2) are analyzed hereafter regarding the change compared to the reference scenario.

Table 2. Cattle population and GHG emissions simulated by the national cattle herd model for 6 scenarios, described in Table 1, reflecting three types of intensification.

	REF	DI+	DI-	N100	N100V-	YB+	S+
Cattle population (M head)	19.4	19.0	19.2	19.7	18.6	18.4	19.6
Beef cows	4.6	5.2	5.3	3.5	2.9	4.4	4.3
Dairy cows	3.4	2.6	2.6	4.3	4.3	3.4	3.4
Direct GHG emissions							
kg eq. CO_2/kg carcass	30.28	29.66	30.11	30.58	29.06	28.87	30.47
% REF scenario		-2.03	-0.56	0.99	-4.01	-4.66	0.65

Increasing PH milk yield (DI+) led to a decrease in the number of dairy cows (-0.8 M) and an increase in the number of beef cows (+0.6 M). Globally, both cattle population and GHG emissions decreased (-2.60%). When PH numerical productivity decreased (DI-), more beef cows were needed to achieve the meat production objective. Hence, the cattle population and GHG emissions decreased less than in DI+ (-0.56%). A 100% N breed dairy herd (N100) led to an increase in the number of dairy cows since this breed is less productive, and more cows are needed to achieve the milk objective. Even though the number of beef cows decreased, total cattle population increased, as did its GHG emissions (+0.99%). Finishing N calves as YB or S instead of V (N100V-) led to a decrease in cattle population (-0.8 M) and GHG emissions (-4.01%). Finally, increasing the number of YB (YB+) decreased both cattle population (-1.0 M) and GHG emissions (-4.66%). Conversely, increasing the number of S (S+) slightly increased the cattle population (+0.2 M) and the GHG emissions (+0.65%). YB and S had similar carcass weight, but S lives one year longer, thus increasing the number of animals in demographic categories.

2.2. Discussion: Results suggest that dairy or beef herd intensification led to slight effects on GHG emissions; they thus contrast with those of previous studies (Capper *et al*., 2008). This difference may come from assuming the beef herd increase compensates for the dairy herd decrease to ensure the same production objective (Zehetmeier *et al*., 2011). The apparent contradiction in intensification efficiency for mitigating GHG emissions highlights the importance of defining the organization level addressed and the system boundaries when evaluating environmental impacts. The effect of a factor at a given level cannot be simply extrapolated to other levels. Our results also show that finishing types have an impact on GHG emissions. Reducing finishing time reduces the number of animals in age classes and thus GHG emissions. However, such results should be nuanced in terms of carbon footprint; our model considered only direct GHG emissions and not emissions due to inputs. It will be necessary to link finishing types with their diets to evaluate the indirect emissions associated with a type of meat product.

CONCLUSION: The national cattle herd model quantifies the effects of different technical options on the national inventory of GHG emissions under a constant production objective. Results show that integrating the interactions between beef and dairy herds, through meat co-production, modifies the efficiency of animal dairy intensification as a GHG mitigation option, which could be cancelled by a reduction in numerical productivity. The results also highlight the potential interest of different finishing types in reducing GHG emissions.

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A LOW-COST DATABASE AND SOFTWARE FOR THE MEASUREMENT OF AMMONIA AND GREENHOUSE GAS EMISSIONS OF ANIMAL HOUSES

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ABSTRACT: Measuring the emissions of thousands of animal houses is needed to obtain representative emission factors and relevant categories of animal farms for emission inventories. This scale is also necessary to develop a comprehensive understanding of all facotrs that influence ammonia and greenhouse gas emissions at the farm scale. A robust and low-cost method was developed in France to measure emissions from poultry, bovine and swine houses. A database and associated software is presented here that helps to apply this method to a large number of houses, while protecting the data when the database is used by different companies or institutions. It is based on freeware: an Ubuntu system, OpenOffice for testing equations, PostgreSQL and PgAdmin for database management with "user-only" or "project-only" restricted access to data, and C++ with CodeBlocks and wxWidgets for the calculation and interface modules developed. As for typical Ubuntu software, all messages in the interfaces developed can be translated into several languages using PoEdit. All systems, software and data can be stored on a bootable USB flash drive or SD card with at least two partitions, one for the system (FAT32) compressed into a squashfs file, and one for the modified files (EXT2). The data are divided into three categories: national references (e.g. manure composition), farm references (e.g. specific house characteristics), and observations (e.g. gas concentrations). Training is recommended to begin using the software more quickly. Further development is required to adapt this tool to monitor the results of mitigation strategies and improve their efficiency.

Keywords: database, NH_3, GHG, emission, measurement, inventory, low-cost method

INTRODUCTION: As stated in IPCC 2006 Guidelines, "the best way to determine emission factors is to conduct non-invasive or non-disturbing measurements of emissions in actual systems representative of those in use in the country" (IPCC, 2006). Emission factors depend greatly on livestock and manure management practices: in the case of N_2O emissions, IPCC (2006) proposes values ranging from less than 0.001 to above 0.1 kg N_2O-N (kg N excreted)$^{-1}$. The high uncertainty (factor 2 for N_2O, IPCC 2006) shows that the variability within any one category remains high. Measuring the emissions of thousands of animal houses is a strategic issue for improving emission inventories and mitigation strategies. It will improve the choice of relevant categories of animal farms, animal numbers and emission factors associated with each category. Identifying and understanding the differences between categories will improve the knowledge of practices that reduce ammonia (NH_3) and greenhouse gas (GHG) emissions at the farm scale. Monitoring emissions in a large number of

animal houses over years will help reveal emission reductions independent of animal numbers.

A robust and low-cost method was developed in France to measure emissions in animal houses. The measuring principle is non-disturbing. It can be applied in mechanically or naturally ventilated houses for NH_3 or GHG emissions and was adapted for bovine (Hassouna et al., 2010), poultry (Ponchant et al., 2009) and swine (Guingand et al., 2011) houses. This method could be applied to a large number of animal houses if a standard software offered the ability to store farm data and use it to calculate emissions in a homogeneous manner. The objective of this paper is to propose an initial set of software, including a database for observations and programs to calculate emissions, for the management of NH_3 and GHG emission data in a large number of animal houses.

1. MATERIAL AND METHODS:

1.1. Measuring principle: The method's principle is based on the general law of convective transfer through an opening (eq. 1) and on two hypothesis: (i) most carbon (C) is lost as CO_2 (eq. 3), (ii) variations in NH_3 and GHG emissions follow variations in CO_2 emission:

$$\text{emission} = \text{ventilation} \times (\text{concentration inside} - \text{concentration outside}) \quad \text{[eq. 1]}$$

$$\text{therefore: } \frac{\text{emission } CO_2}{\text{emission } NH_3} = \frac{\text{concentration } CO_2 \text{ inside} - \text{concentration } CO_2 \text{ outside}}{\text{concentration } NH_3 \text{ inside} - \text{concentration } NH_3 \text{ outside}} \quad \text{[eq. 2]}$$

when most carbon is lost as CO_2 through animal respiration, CO_2 emission can be estimated by: $\text{emission } CO_2 = (\text{input C} - \text{output C}) \times \frac{44}{12}$ [eq. 3]

On each farm, gas observations inside and outside the animal houses are supplemented with climate observations and a farmer questionnaire. The mass balance of C is estimated using national references or specific observations of feed, animals, manure and litter. When the ratio of concentration gradients used in eq. 2 is stable during a period in which C loss can be estimated, the emission of NH_3, GHG or water can be estimated with eq. 2. The value of CO_2 emission in eq. 2 is then replaced by the value estimated with eq. 3.

Uncertainties in emission estimates are mostly due to (i) the representativity of national references and feed information used to calculate the mass balance of C and (ii) the temporal representativity of one gas observation to the period when it is applied. The former can be reduced by performing expensive mass balance surveys, including mass and concentration measurements of animals, feeds and manure. The latter can be reduced by repeating the measurements or performing expensive continuous gas and climate monitoring inside and outside the houses.

In France, the variability in the ratio of concentration gradients used in eq. 2 is high: from less than 10 to above 10000 when considering NH_3, CH_4 and N_2O gradients in swine, poultry or dairy cattle houses. This indicates that emissions can vary by a factor of 1000 for a given animal's respiration. Therefore, despite simplifications and uncertainties, we consider that this low-cost method can help identify emission categories relevant to national diversity.

1.2. Factors explaining emission variability: In most countries with a tradition of animal farming, there is a high diversity of livestock and manure management practices and existing databases. The following factors influence emissions and can be used to improve the definition of farm categories; some are directly included in the proposed database. Emission of nitrogenous species (NH_3, N_2O, and N_2) depends on the nitrogen content of the feed and animal production. Changes in stocking density modify NH_3 and GHG emissions. Emissions from manure vary with dilution of excretion by water or litter addition. Emissions depend on air temperature and manure dry matter content. Other factors can be identified by linking this database to other existing databases on a farm basis. The farm's crop area and herd size influence farmer practices: in France both can vary within a large range (Agreste, 2011). The number of animal species combined on one farm is higher on small farms, while genetic diversity is smallest on the largest animal farms: this diversity influences feed conversion ratio, efficiency of local resources and manure management. Animal feed can be produced on the farm or imported. In poultry confined-feeding operations, manure is mostly solid, while it is liquid in most swine systems (CITEPA, 2012). Solid manure is more easily exported than liquid manure. On farms where most feed is imported and manure is liquid, decreased efficiency of nitrogen recycling and higher nitrogen losses are observed at the farm scale.

The complex influence of these factors is linked to the various time and spatial scales of the concerned processes. This complexity is also due to positive or negative biological feed-back that interacts with farmer management practices and the climate. Associating many factors with emission values observed on a large number of animal farms can help improve national emission categories. Comparing categories can help identify low-cost practices that currently reduce emissions. Transferring these practices to farms can reduce the cost of mitigation strategies compared to large-scale investments.

2. RESULTS AND DISCUSSION:

2.1. Database and datasheet design: A database for a large number of houses and datasheets for single houses were implemented with the same rules (Figure 1). The data come from three source types: national references (e.g. manure composition), farm references (e.g. specific house characteristics), and observations (e.g. gas concentrations). All sources can be used for mass balance estimates. Mixing observations and national references (e.g. observed concentrations in manure with references for mass values) can increase uncertainty in emissions. The conservation of phosphorus and potassium should be checked before using farm data to calculate the mass balance of N or C. When water consumption is observed, the water deficit can confirm the water emission.

2.2. Software development: The software was implemented using open source freeware. PostgreSQL and PgAdmin were installed on an Ubuntu operating system, with "user-only" or "project-only" restricted access to data. C++ software for data input and calculations were implemented with CodeBlocks and wxWidgets. All messages of the developed interfaces can be translated into different languages using PoEdit. A bootable USB flash drive contains all the software. It uses a system compressed into a squashfs file and a modifiable partition (EXT2) to store current work.

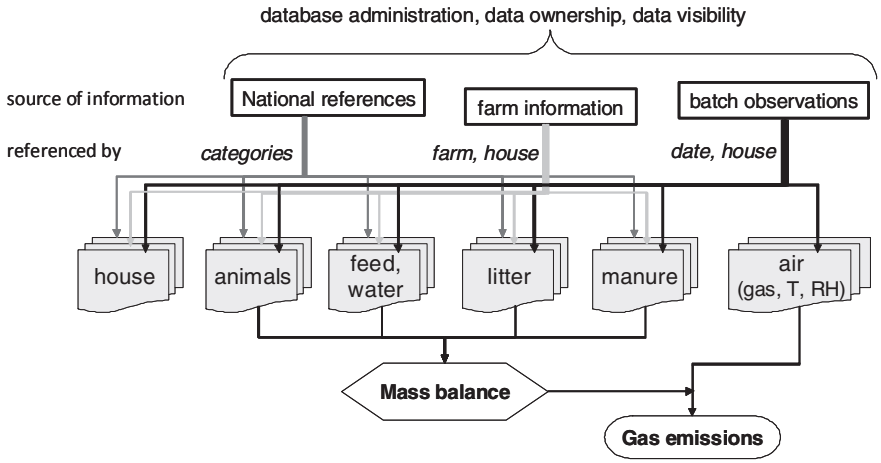

Figure 1. Source and flow-chart of the database/datasheet information.

CONCLUSION: Software and a database were developed to provide tools for monitoring emissions in a large number of animal houses. It was developed on a bootable USB flash drive using open source freeware. It combines OpenOffice datasheets for flexible use with a small number of farms with a PostgreSQL database with C++ input and calculation programs for standard application to a large number of farms. Training is recommended to begin using the software more quickly. Further development is required to adapt this tool to reduce the costs of mitigation strategies on the basis of observed efficient practices.

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EFFECT OF FORAGE REGIME AND CATTLE GENOTYPE ON THE GLOBAL WARMING POTENTIAL OF DAIRY PRODUCTION SYSTEMS

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ABSTRACT: The aim of this study was to assess, by Life Cycle Assessment (LCA), the effect of forage regime and cattle genotype on the global warming potential (GWP) of conventional dairy production systems. Two feeding regimes (low forage vs high forage) were applied to each of two genetic lines (Control and Select genetic merit for milk fat and protein), giving four contrasting production systems assessed over seven years. Key factors in the difference between systems were high off-farm gross CO_2e emissions in the low forage regime (due to feed imports) and high N_2O emissions in grazing systems (owing to increased land, fertiliser, excreted nitrogen and deposition at pasture). Higher gross emissions in low forage group and Select genetic line were offset by high productivity. Both improving genetic merit of the dairy herd and implementing the low forage system lowered GWP per unit ECM.

Keywords: dairy, forage, genotype, greenhouse gas, life cycle

INTRODUCTION: Dairy production systems are a significant contributor of anthropogenic greenhouse gas (GHG) emissions. Components of the total GWP of dairy production systems arise from processes both on and off the farm. These include enteric methane (CH_4) direct from livestock, emissions from liquid and solid animal wastes, agricultural soils and from decomposition of crop residues. In addition, GHG are also emitted in the external production and transport of animal feeds and inorganic fertilisers. For the dairy industry to meet the growing global demand for dairy products, ways to minimise GHG emissions per unit product in a sustainable manner will become increasingly important. Increasing the efficiency of livestock production through animal breeding and nutrition are some of the most promising ways to reduce GHG emissions (Steinfeld et al 2006). It has been shown that high yielding dairy cows with high feed intakes are associated with a lower enteric CH_4 output per unit milk (Bell et al 2010); therefore, herd numbers may be optimised for level of production. Chagunda et al (2009) showed that although increasing milk production was associated with a reduction in enteric CH_4 per milk unit, excreted waste nitrogen could increase both per milk unit and per hectare land used, depending on the genetic merit of animals and the specifics of the production system. Therefore, the overall GHG pollution potential from dairy production systems is a dynamic process which should be assessed at a whole-systems level to optimise the total output of pollutants against productivity. The aim of this study was to assess, by way of LCA, the effect of forage regime and cattle genotype on the GWP of dairy production systems within a conventional farm.

1. MATERIAL AND METHODS: The study was based on Scottish Agricultural College's (SAC) established long-term Holstein-Friesian genetic and management systems project, situated at SAC Dairy Research Centre, Crichton Royal Farm, Dumfries. Data used were collected over the period of January 2004 to December 2010, and incorporated specifics of four distinct systems within a conventional farm. Animals were maintained in two feeding groups, high forage (HF) and low forage (LF). The HF systems aimed to provide 75% of dry matter of the herd's mixed ration diet from home- grown crops (ryegrass silage, whole crop maize, wheat alkalage) and 25% of ration composition from purchased concentrated feeds (distillers grains,

rapeseed meal). Cows in the HF systems were turned out to graze ryegrass pasture when available, and therefore, the total home grown element of the annual HF diet was nearer to 85%. In contrast, the LF systems were fully housed; the herd retained indoors all year and fed a diet of approximately 45% home-grown forages, with 55% of the diet from purchased concentrates (wheat, sugar beet pulp, soya) imported onto the farm. Within each forage system, animals comprised two contrasting genetic lines. Control (C) animals were bred of average UK genetic merit for milk fat and protein production, and Select (S) animals represented the top 5% of UK genetic merit. Maintaining the specifics of these groups in a long term genotype x feeding regime project resulted in four divergent dairy production systems – HFC, HFS, LFC and LFS. These systems are representative of the interaction between forage regime and genetic line. Cows were milked three times daily, received equal treatment regarding health and fertility, and herd numbers maintained at approximately 50 cows in each system. S and C cows were managed together and groups retained in the same building when housed. All young stock were managed together.

1.1. Life Cycle Assessment: Currently, LCA stands as the preeminent tool accounting for environmental impacts of products and their processes within a specified boundary. The systems within this study covered the life cycle required for the production of raw milk, from the on- and off-farm production of system inputs, to product leaving the farm-gate. On-farm system inputs included herd dynamics, productivity, energy, application of inorganic fertilisers, land use, cropping and feed intake. Off-farm inputs included the cost of production and transport of inorganic fertilisers, imported concentrated animals feeds and bedding. Impact assessment was conducted using a modified version of SAC Carbon Calculator vII (RBU 2011), designed specifically for use in the Scottish agricultural sector and implementing IPCC tier II methodology (IPCC 2006). Liaising closely with the developer, this study was able to implement tier III methodology to properly define specific differences among the four dairy production systems. GWP, the environmental impact category for this study, was expressed in terms of $kgCO_2$-equivalents. The primary function of dairy systems is milk production; therefore, the functional unit (FU) chosen to reference the GWP was "1 kg of energy corrected milk (ECM) leaving the farm gate". A breakdown of system component contributions to the GWP per kgECM is displayed in Table 1. Total area of farm land in hectares (ha) required to fulfil each system was also assessed as a second FU for relative systems efficiency.

Table 1. Descriptive statistics for components of Life Cycle Assessment output, expressed as kg carbon dioxide equivalents per kg energy corrected milk ($kgCO_2e\ kgECM^{-1}$).

Component	LFC		LFS		HFC		HFS	
	mean	sd	mean	sd	mean	sd	mean	s
Fossil fuels	0.06	0.01	0.05	0.01	0.06	0.01	0.05	0.0
Electricity	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.0
In. fertiliser production	0.06	0.01	0.05	0.01	0.09	0.03	0.08	0.0
Purchased feed & bedding	0.19	0.01	0.16	0.01	0.16	0.01	0.14	0.0
Enteric fermentation	0.54	0.02	0.45	0.03	0.64	0.04	0.53	0.0
Animal wastes CH_4	0.06	0.02	0.06	0.02	0.09	0.01	0.08	0.0
Animal wastes N_2O	0.09	0.00	0.08	0.01	0.16	0.02	0.13	0.0
In. fertiliser application	0.04	0.01	0.04	0.01	0.07	0.02	0.06	0.0
Crop residues	0.04	0.00	0.03	0.00	0.05	0.00	0.05	0.0
Milk yield (kgECM cow^{-1})	9246	800	10753	853	7281	533	8189	65
Farmland required (ha cow^{-}	0.52	0.08	0.60	0.08	0.73	0.11	0.76	0.1

1.2. Statistical Analysis: The relative efficiency of systems was assessed using analysis of variance (ANOVA). The most efficient system was determined as having the lowest GWP per FU. The general linear model used to assess effects of forage regime and genotype on GWP was: $y_{ij} = \mu + G_i + F_j + (GxF)_{ij} + Y_{ij} + \varepsilon_{ij}$ where y_{ij} is the

total global warming potential of the dairy production system per kg ECM and per hectare farmland; μ is the overall mean; G_i is the fixed effect of genetic line (Control or Select); F_j is the fixed effect of the feeding system (Low Forage or High Forage); $(GxF)_{ij}$ is the effect of interaction of forage and genetic line; Y_{ij} is the fixed effect of calendar year; ε_{ij} is the random error term. All statistical analysis was conducted using Minitab 16.

2. RESULTS AND DISCUSSION: In all years, LFS was found as the most efficient system per milk unit ($P<0.001$). The HFC system, representative of a typical UK dairy farm, was found least efficient in all years. Results from ANOVA are presented in Table 2. Average LFS milk yield was observed as 48% higher than HFC, therefore productivity was a key factor. Using ECM as a functional unit, the total overall GWP was 18% lower in LF and 14% lower in S groups. Effect of both forage regime and genotype on the overall GWP were highly significant ($P<0.001$). The interaction term was not significant. The results suggest that there is potential to reduce the GWP per unit productivity of a typical conventional UK dairy system by up to 30%. Improving the herd genetic merit could potentially bring a 14% reduction in the GWP per productivity unit. Improvement necessarily proceeds gradually and would realistically take several years to return results. Results also suggest that switching to the low forage system holds potential for a reduction in GWP of up to 18% per productivity unit. When using area of farmland as a functional unit, the effect of forage regime on total GWP was significant ($P<0.001$). HF was more efficient than LF but S was not significantly different to C. HF groups required an additional 0.18ha cow^{-1} (sd=0.06) land annually due to grazing. HFS was the most efficient system ($P<0.001$) per ha farmland and LFC the least.

CH_4 made the highest contribution to GWP of all systems (50-57%). Although gross enteric CH_4 was 7% less per cow in HF, when referenced to productivity the GWP of enteric CH_4 from HFC was around 40% higher than LFS. Under the fully housed regime, 100% of the milking herd excreta was stored under anaerobic conditions as liquid slurry, resulting in higher gross manure CH_4. Despite this, LF groups were still observed as more efficient in terms of manure CH_4 per unit ECM. In all groups, N_2O emissions were greatest from excreta, followed by emissions from inorganic fertilisers and thirdly from crop residues. The contribution of N_2O from inorganic fertilisers was lower than expected. This can be explained by a comparatively low application rate of inorganic nitrogen (87kg N ha^{-1}, sd=22), resulting from more efficient use of fertilisers by implementing slurry injection. Gross emissions relating to the application of inorganic fertilisers were higher for the outdoor HF systems, owing to additional grassland requiring management for grazing. Gross nitrous emissions from animal excreta were also considerably higher from the HF systems, owing to greater waste excreted nitrogen per cow and an emissions factor 20 times higher for deposition of animal wastes at pasture compared with liquid storage (IPCC 2006). When referenced against productivity, HFC produced double the N_2O from animal wastes compared with LFS and 59% higher emissions from applied inorganic fertiliser. Quantities of home-grown forage crops required by all systems were broadly similar, thus emissions associated with crop residues were comparable across all groups. However, increased productivity of LF again led to lower GWP per milk unit. Contribution of embedded emissions in imported feeds and bedding was 48% proportionally higher in LF. However, this is in line with expectations of a fully housed system, as opposed to the grazing groups which spent an aggregate 148 (sd=15.5) full days at grazing annually. The imported feed and bedding component of the systems' GWP dynamic was the only contributing category to remain higher in LF than HF when referenced to milk production. As with the associated N_2O emissions, the embedded CO_2e in imported

inorganic fertilisers were lower in LF groups, owing to increased fertiliser requirement of the grazing system. Gross emissions were 27% lower in LF and the margin widened when referenced to kgECM.

Table 2. Least squares means for global warming potential per kg energy corrected milk and per hectare farmland of forage regime, genetic line and dairy production systems.

Variable	Level	$kgCO_2e\ kgECM^{-1}$	$kgCO_2e\ ha^{-1}$
Forage regime	Low (LF)	1.02[a]	18595[h]
	High (HF)	1.25[b]	13691[i]
	sem	0.016	616.2
Genetic line	Control (C)	1.23[c]	16575[j]
	Select (S)	1.05[d]	15711[j]
	sem	0.016	616.2
System	LFC	1.10[e]	19099[k]
	LFS	0.94[f]	18091[k]
	HFC	1.35[g]	14051[l]
	HFS	1.15[e]	13331[l]
	sem	0.023	871.5

Different superscripts within a column denote significant differences between levels of same variables ($P<0.001$)

CONCLUSION: Key factors in the difference among systems were high off-farm gross CO_2e emissions in LF and high on-farm N_2O emissions in HF. In LF groups, high gross emissions were offset by high productivity, but this was not the case for the more extensive HF groups. Main effects of both forage regime and genotype were individually significant when GWP was referenced to productivity. Both improving genetic merit of the dairy herd and implementing a low forage system lowered GWP per unit ECM.

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Part VII.
Invited Paper

Invited Paper

EMISSION AND DISPERSION OF BIO-AEROSOLS FROM LIVESTOCK HOUSING

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ABSTRACT: The air of modern livestock houses can contain high amounts of a large variety of air pollutants such as odours, gases, dust and micro-organisms which are also summarizing addressed as bio-aerosols. These bio-aerosols are widely recognised as detrimental for the respiratory health of animals kept in these facilities and the work force working regularly in this atmosphere. Concerns are growing that these bio-aerosols when emitted by the ventilation system into the environment may contribute to respiratory disorders in residents living close to farm animal enterprises. However, little is known about role, fate and survival time of emitted bio-aerosols in the surrounding of farms, transmission distances, dispersion in ambient air and deposition at various distances around the farm. Similarly, little is known about practical abatement techniques to either avoid or reduced emissions. This paper gives a brief overview on characteristics and amounts of bio-aerosols in animal houses, refers to some appropriate methods of sampling and discusses survival times of bacteria in an airborne state, their possible travel distances in the surrounding of farms and reflects on "safe distances" between animal houses and residential dwellings and looks for appropriate abatement options for bio-aerosol emissions. Recent experimental data are presented which show that bacteria like *Staphylococcaceae* can be found airborne about 500m downwind of a broiler barn in significant concentrations (4000 cfu/m³) and MRSA (meticillin resistant *Staphylococcus aureus)* were detected qualitatively on soil surfaces 300 m downwind of a piggery. Abatement techniques like biofilters and biowashers (end-of-pipe technology) can reduce airborne bacterial emissions from piggeries by approx. 90%. There is an urgent need for the further development of low emission animal houses. Reducing air pollutants in animal houses will provide a healthier work environment for employees and a better atmosphere for the animals improving their health, welfare and performance and has the high potential to lower emissions and to avoid complaints from nearby residents. Future-oriented sustainable animal farming systems have to take into account - beside the topics of animal health and welfare, consumer expectations for cheap and safe food, economy and ecology - also standards to prevent or reduce the spread of pathogens via the air.

INTRODUCTION: The production of pig and poultry meat has doubled in the last 30 years worldwide following the demand of a fast growing world population for food of animal origin (Rae and Nayaga, 2010). Such increase was only possible by a significant intensification of the production systems keeping large numbers of animals in specialised farm buildings. This type of modern animal production is increasingly regarded as a source of solid, liquid and airborne emissions which can be both aggravating and environmentally harmful (e.g. Aneja et al., 2008; Hartung and Wathes, 2001; Jarvis and Pain, 1990).

The air of such modern livestock houses can contain high amounts of a large variety of air pollutants such as odours, gases like ammonia and carbon dioxide, dust, fungi and bacteria including zoonotic agents, endotoxins and allergens (Dungan and Leytem, 2009; Seedorf and Hartung, 2002; Hartung, 1998) which are also addressed as bio-aerosols (Hirst, 1995) because of their predominantly organic origin and

complex nature. These bio-aerosols give cause for concern for several reasons. Firstly, there is strong epidemiological evidence that the health of farmers working in animal houses may be harmed by regular occupational exposure to bio-aerosols. For example, a number of 3219 respiratory disorders in farm workers caused by allergic, chemical irritative or toxic substances in the air of animal houses were reported 2009 in Germany (DGUV 2011). Secondly, an animal's respiratory health can be negatively affected by these pollutants. In some herds, half of all slaughter pigs may show signs of pneumonia, pleuritis or other respiratory disease. The third reason for concern is that these aerial pollutants emitted from livestock buildings into the environment are increasingly a source of complaint from people living in the vicinity of livestock farms assuming that their respiratory health may be compromised by dust and micro-organisms (Millner, 2009; Bull et al., 2006; Hartung and Schulz, 2008; Madelin and Wathes, 1989; Whyte, 1993).

While there are increasing data on types and amounts of air pollutants in animal houses, there is a considerable lack of knowledge about the emission amounts, dispersion, particularly the travel distances, deposition dynamics and transmission of bio-aerosols and their compounds like bacteria from livestock buildings in the environment. One reason for this shortage in knowledge is the lack of suitable sampling techniques and strategies for outdoor measurements of bio-aerosols and that there is still little knowledge about their nature and composition, the tenacity (resistance) of bacteria and viruses in an airborne state and their survival times in ambient air. Similarly, little is known about the retention efficiency of the recently in some countries propagated and used exhaust air purification systems for compounds like micro-organisms and endotoxins such as biofilters and biowashers (e.g. Hartung and Clauß, 2011).

This paper gives a brief overview on characteristics and amounts of bio-aerosols, refers to some appropriate methods for sampling and discusses survival times of bacteria in an airborne state, their possible travel distances in the surrounding of farms and reflects on "safe distances" between animal houses and residential dwellings and looks for appropriate abatement options for bio-aerosol emissions.

1. AIRBORNE POLLUTANTS IN FARM ANIMAL HOUSES AND DEFINITION OF BIO-AEROSOL: The key pollutants recognised in the airspace of livestock buildings are particles including dust, microorganisms and their toxins, and gases such as ammonia, carbon dioxide and more than 100 trace gases e.g. like volatile fatty acids and many more (Table 1). Under commercial production conditions the airborne particles will contain a mixture of biological material from a range of sources, with bacteria, toxins, gases and volatile organic compounds adsorbed to them. Because of their complex nature these airborne particles are also addressed as bio-aerosols (Seedorf and Hartung, 2002; Hirst, 1995).

Table 1. Overview of common air pollutants in animal houses.

Gases	Ammonia, hydrogen sulphide, carbon monoxide, carbon dioxide, 136 trace gases, osmogens
Bacteria/Fungi	100 bis 1000 cfu/l air 80 % staphylococcaceae/streptococcaceae
Dust	e.g. 10 mg/m³ inhalable dust organic matter approx. 90 %, antibiotic residues
Endotoxin	e.g. 2000 EU/m³ in piggeries (EU=Endotoxin Unit)

Several studies have recorded concentrations of key components of bio-aerosols in farm animal buildings, but with particular high amounts in poultry production (e.g. Seedorf et al., 1998). Table 2 summarises the results of a broad EU-wide study on bio-aerosols in pig, cattle and poultry farms. The results show that the lowest concentrations were found in cattle production and the highest in poultry houses (Seedorf et al., 1998). However there are existing considerable differences between production systems within one species. The highest dust concentrations regularly occur in aviaries for laying hens. These concentrations often exceed the occupational health limit at the work place of 4 mg/m³ (for Germany) particularly at times of high animal activities (Saleh, 2006). These pollutants are emitted into the environment by way of the exhaust air through the ventilation system.

Table 2. Average Bioaerosol Concentrations in Livestock Buildings.

		Cattle	Pig	Chicken
Inhalable Dust	mg m^{-3}	0.38	2.19	3.60
Respirable Dust	mg m^{-3}	0.07	0.23	0.45
Total Bacteria	log CFU m^{-3}	4.4	5.2	5.8
Total Fungi	log CFU m^{-3}	3.8	3.8	4.1
Inhalable ETOX	ng m^{-3}	23.2	118.9	660.4
Respirable ETOX	ng m^{-3}	2.6	12.0	47.5

ETOX: Endotoxin, 1 ng equals approx. 10 EU (endotoxin units);
CFU: Colony forming units
(Seedorf et al. 1998, Takai et al. 1998; modified)

1.1. Some characteristics of bio-aerosols in livestock houses: Bio-aerosols in livestock buildings consist of a complex mixture of organic materials (i.e. proteins, polycarbohydrates), biological active components (i.e. endotoxins, glucans) and micro-organisms (i.e. bacteria, fungi). Even gases such as ammonia can be adsorbed to the surface of bio-aerosol particles. Typically, bio-aerosols are characterised by a range of biological properties which include infectivity, allergenicity, toxicity and pharmacological or similar effects (Hirst, 1995). Their sizes can range from aerodynamic diameters of 0.5 to 100 µm (Hirst, 1995). These small particles can also carry residues of antibiotic drugs. Hamscher et al. (2003) showed that dust in piggeries can contain various antibiotics including tetracyclines, sulfonamides, tylosin

and chloramphenicol, and in some samples the concentrations reached 12.5 mg/kg animal house dust.

2 SAMPLING AND ANALYSIS OF BIO-AEROSOLS : Most sampling methods for bio-aerosols are based on the principles of sedimentation, filtration, impingement and impaction. Sedimentation uses the gravitational forces depositing airborne particles on different kinds of surfaces. The sedimentation process is influenced by a variety of factors such as the aerodynamic diameter and the specific density of the particle and the velocity of the ambient air. For that purpose nutrient media or other adhesive surfaces are used. Although sedimentation techniques are simple to perform the data cannot be related an air volume (only to surface) and sedimentation favours the sampling of larger particles due to their sedimentation behaviour.

The collection of airborne bacteria by filtration is widely used. Filters are usually fixed in cassettes or sampling frames and the air is sucked through with flow rates from a few litters to several m³ per hour depending on sampling system and aim of the measurement. For endotoxin sampling e.g. glass fibre filters and for micro-organisms polycarbonate filters with defined pore sizes can be used. A considerable problem of the filtration technique is the rapid desiccation of deposited bacteria on the filter surface limiting survival times. Therefore sampling times should be as short as possible, but long enough to collect sufficient micro-organisms on the filter for detection and analysis. The use e.g. of gelatine filters can help to prevent premature loss of bacterial vitality.

Impingers are very effective in sampling airborne micro-organisms. They are usually made of glass filled with a liquid which serves as sampling medium. The air is sucked by means of pumps through the liquid and the particles are stripped of the air stream and enrich in the liquid. Aliquots of the liquid are taken for microbiological analysis. The grown colonies are counted and the results are given in cfu per litre of air. The All-Glass-Impinger 30 (AGI-30) is one of the standard bacterial aerosol sampler (Brachman et al., 1964). A sampling rate of 12.5 l min^{-1} is used and the volume of the sampling liquid in the impinger varies between 20 and 60 ml. The advantage of the impinger technique is that viable micro-organisms are collected rather gently in the sampling fluid. A major limitation for outdoor sampling is the relative low flow rate. Long sampling times cause problems by evaporating sampling liquids or increased sampling stress of the first sampled micro-organisms. Measurements at low ambient temperatures need tempered impingers to avoid ice formation (Springorum et al., 2011).

Impaction based measurements are usually designed for short or medium term sampling of bacteria. In principle, the air is drawn through a specifically designed opening (slit, hole) at a given speed. The particles are accelerated and impact on the surface of a fixed or slowly rotating agar surface (e.g. Petri dish) directly under the opening (e.g. Pahl et al., 1997). After incubation the grown colonies are counted and given in cfu per litre of air. Frequently used are the hand held Reuter-Centrifugal-Sampler (RCS) (Platz et al., 1995) and the Andersen impactor which is able to separate particles in different particle size classes. Desiccation of the agar surface during longer sampling and storage times and relative low air throughputs in the instrument limit the use of this technique for outdoor measurements. Recently an impactor was described using silicon surfaces by which microorganisms can be analysed within minutes (Clauß et al., 2010; Clauß et al. 2012).

3. TRANSMISSION DISTANCES OF BIO-AEROSOLS IN AMBIENT AIR : There are only a limited number of experiments carried out on transmission distances of bio-aerosols from animal confinements. From epidemiological studies it is known that FMD-virus can travel over distances of more than 50 kilometres (i.e. Donaldson and Ferries 1975, Gloster et al., 2005). Experiments around farms revealed elevated levels of dust particles and bacteria in comparison to reference point measurements between 50 and 115 m and 50 and 300 m, respectively (Table 3). These figures are far from being safe distances because they do not reflect the spread of specific pathogens or allergenic components (e.g. feather fragments) which may be transported much longer distances, and which can develop health risk even in small quantities.

Table 3. Reported transmission distances of bio-aerosols emitted from livestock buildings.

	Distance, m	Animal species	Reference
Dust particles	50	Poultry	Schmidt & Hoy (1996)
	115	Piggery	Hartung et al. (1998)
Bacteria	50	Piggery	Platz et al. (1995)
	100	Poultry	Sarikas (1976)
	200	Piggery	Holmes et al. (1996)
	200-300	Poultry	Müller & Wieser (1987)

Most important for a possible transmission of a pathogen is its ability to survive in an airborne state over a longer period. Micro-organisms in an air-borne state are strongly influenced by environmental conditions such as temperature and humidity of the air. Other factors are radiation, sun light and additional chemical compounds in the air. For dispersion wind direction and wind speed play the most important role.

3.1. Measurement of Staphylococcaceae downwind from broiler barn : Recent investigations in and around broiler houses showed that the travel distance of Staphylococcaceae downwind can be at least 500 m from the source. Under stable wind conditions more than 4000 cfu/m³ were found 477 m downwind the barn (Figure 1). Staphylococcaceae are typical bacteria in broiler house air. They can probably serve as indicator bacteria for the bacterial pollution because they do usually not appear in relevant concentrations in normal outside air.

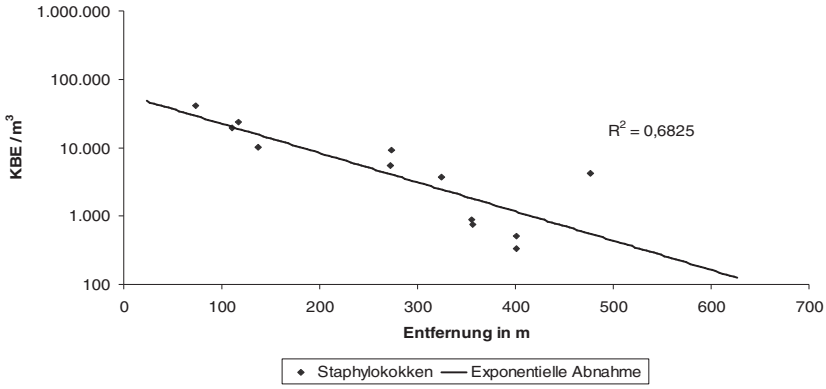

Figure 1. Decreasing concentrations of Staphylococcaceae with increasing distance downwind a forced ventilated broiler barn with 30,000 birds. Sampling 1.5 m above ground. Animals in second half of production cycle. Air temperature about 16 °C, wind speed between 1.7 m/s and 6.3 m/s. n = 12. (Schulz et al. 2004).

However, it seems that the type of ventilation in the barn can play a role in regard to the dispersion. Table 4 shows the results from six samplings taken simultaneously in the barn and downwind from the barn at different distances.

The experiments were carried out inside and in the vicinity of a naturally ventilated Louisiana type broiler barn, housing nearly 40.000 broilers (Ross hybrid broilers) on straw litter during three subsequent fattening periods (growing cycle) in a summer season. The barn was situated in a typical rural area of the north of Germany surrounded by arable land and meadows. Air samples were taken during the second half of three fattening periods with Impinger (AGI-30) in the barn and simultaneously upwind and downwind from the building. Staphylococci concentrations varied between 1×10^6 and 1×10^7 cfu·m^{-3} in the barn. A strong exponential decrease of these bacteria was observed at three sampling heights (1.5, 4.0 and 9.5 m) in the main wind direction downwind of the barn. Staphylococci concentrations up to 5.9×10^3 cfu·m^{-3} were detected at the farthest sampling point (333 m) downwind. Identification to the species level by means of a 16S-23S ITS PCR confirmed that *Staphylococcus* spp. from downwind samples originated from the barn. Inside and downwind from the animal house almost the same *Staphyloccoccus* species were found which strongly indicates that the bacteria sampled at the different distances in the main wind direction really originate from the broiler barn. This is supported by the fact that no staphylococci could be detected on the upwind control side. Seven different coagulase negative *Staphyloccoccus* species were identified. Most species (except *S. lentus*) such as *S. cohnii,* S. *saprophyticus*, *S. arlettae* and *S. xylosus* are phylogenetically closely related and belong to the *S. saprophyticus* group, based on 16S rRNA gene sequence analysis (Takahashi et al., 1999). *S. warneri, S. caprae, S. xylosus* and *S. lentus* were found as single colonies only. Their detection was in the range of the detection limit of the impingement.

Table 4. Airborne Staphyloccoccus spp. simultaneously detected in the animal house air and at downwind sampling points of a naturally ventilated broiler barn (Schulz et al., 2011).

Growing cycle, distance to the barn	Species detected downwind from the barn	Species detected in the air of the barn
A, 60 m	Staph. arlettae Staph. cohnii Staph. saprophyticus Staph. xylosus Staph. warneri[a]	Staph. arlettae Staph. cohnii Staph. saprophyticus Staph. xylosus Staph. lentus[a]
C, 130 m	Staph. arlettae Staph. cohnii Staph. saprophyticus Staph. caprae[a] Staph. xylosus[a]	Staph. arlettae Staph. cohnii Staph. saprophyticus
A, 221 m	Staph. arlettae Staph. cohnii Staph. lentus	Staph. arlettae Staph. cohnii Staph. lentus
B, 264 m	Staph. arlettae Staph. cohnii Staph. lentus Staph. saprophyticus Staph. warneria Staph. xylosusa	Staph. arlettae Staph. cohnii Staph. lentus Staph. saprophyticus
C, 333 m	Staph. arlettae Staph. cohnii Staph. lentus Staph. saprophyticus	Staph. arlaette Staph. cohnii Staph. lentus Staph. saprophyticus
C, 333 m	Staph. arlettae Staph. cohnii Staph. saprophyticus	Staph. arlettae Staph. cohnii Staph. saprophyticus Staph. lentus[a]

[a] Only a single colony of these species were obtained from the air samples

These results show that there is a measurable distribution of *Staphylococcaceae* from poultry production in the vicinity of livestock houses and that these bacteria could serve as an indicator to demonstrate the travel distance of bacterial emissions originating from naturally ventilated broiler houses.

However, these results cannot be simply applied to forced ventilated broiler barns or laying hen houses (Schneider et al., 2006; Seedorf, 2004). The air exchange rates of naturally ventilated broiler barns can only be calculated by approximation (Formosa, 2005). This makes the use of common dispersion models based on defined emission rates questionable for the spread of airborne microorganisms from naturally ventilated broiler barns. Therefore direct measurements in the ambient air at different distances around animal houses are still the method in case the bacterial dispersion should be characterised qualitatively and quantitatively.

Nevertheless, *Staphylococcus* spp. seem to be suitable as indicator bacteria because they are the dominating airborne bacteria in broiler barns (Hartung and Saleh 2007; Oppliger et al., 2008) originating from the animals and the litter (Devrise et al., 1985; Lu et al., 2003; Shimizu et al., 1992). They are present in high concentrations of 1.2×10^9 and 6×10^9 cfu in one gram of airborne broiler house dust. Hence and due to their relatively high tenacity in the airborne state (Müller and Wieser, 1987) high emissions

of culturable staphylococci can be expected from broiler houses. On the other hand staphylococci apparently do not belong to the typical airborne microflora in the ambient air of rural areas (Deprés et al. 2007; Harrison et al., 2005; Shaffer and Lighthart, 1997).

Table 5 summarises MRSA positive and negative findings upwind and downwind of six MRSA positive pig barns. Inside the barns, all pooled nasal swabs and boot swab samples were MRSA positive. In detail, the number of positive pools from nasal swabs varied between 10 and 12 (out of 12) in all barns. Analyzing 12 single nasal swabs resulted in 5 to 12 positive samples (average was 10). The minimal numbers of single swabs to detect one positive pig with a probability of > 95% ranged from 1 to 5. The intra-herd prevalence was calculated from 47% to 100%. The detection of airborne MRSA failed in three samplings (two in winter and one in autumn) inside the barns. Airborne MRSA was detected 15 times in three impingers, 4 times in two impingers, and 2 times in one impinger. Concentrations of positive air samples (n = 55) varied between 6 and 3619 cfu/m³. The median was 151 cfu/m³ (lower quartile = 45 cfu/m³, upper quartile = 821 cfu/m³). Downwind from the barns, MRSA was detected only in five air samples at three different barns (three in summer, one in spring and autumn). The concentrations of MRSA in these samples were very low, ranging from only 2 cfu/m³ in 150 m (two times) and 14 cfu/m³ (two times) and 11 cfu/m³ in 50 m distances. MRSA was not detected in air samples upwind from the animal houses. Of the boot swab samples taken from soil surfaces downwind of the barns, 73% were positive, compared to only 33% of the upwind soil samples. Boot sampling seems to be an effective method to detect MRSA not only indoors but also in the field. The results indicate that MRSA can be similar distances as we found for MSSA (non resistant *Staphylococcaceae*).

Table 5. MRSA detection in the vicinity of six pig barns. Positive and negative findings[a] during different seasons[b] (Schulz et al. 2012).

Barn no.	Downwind from the barn					Upwind from the barn	
	soil 300m	soil 150m	soil 50m	air 150m	air 50m	air 100m	soil 100m
	Sp. S. A. W.	Sp. S. A. W.	Sp. S. A. W.	Sp. S. A. W.	Sp. S. A. W.	Sp. S. A. W.	Sp. S. A. W.
1	- + + +	- + + -	- - + +	- - - -	- - - -	- - - -	- - o -
2	- + + -	- + - -	- + + +	- - - -	- + - -	- - - -	- + - o
3	+ + - +	+ + - +	+ + - +	- - - -	- - - -	- - - -	- + - +
4	- - + -	+ + + +	+ + + -	- - - -	o - - -	- - - -	- + - -
5	o + o +	+ + + +	o + + +	- + + -	- + - -	o - - -	o + - +
6	+ + + +	+ + + +	o o + +	- - - -	+ - - -	- - o -	o o o -

[a] Findings are expressed as positive (+) or negative (-).o, no sample was taken in this interval.
[b] Abbreviations of seasons: Sp., spring; S., summer; A., autumn, W., winter.

4. OPTIONS FOR ABATEMENT: Figure 2 shows the results of the measurements of bacteria in the in the raw gas from the piggery and in the clean gas behind the air cleaning device. Samples were taken between March and August. The lowest concentrations in the raw gas were seen in early spring of approximately 2×10^5 CFU/m³ and the highest in summer with 18×10^5 CFU/m³. In the clean gas

the lowest concentrations were also found in early spring and the highest in summer. The figures indicate that the three-stage air cleaning device can significantly reduce the bacterial load in the exhaust air of the piggery. However, the figures also show quite a considerable variation in reduction efficiency from sampling to sampling which could not be explained by differences in animal density or technical sampling failures. Average reduction is at 90%.

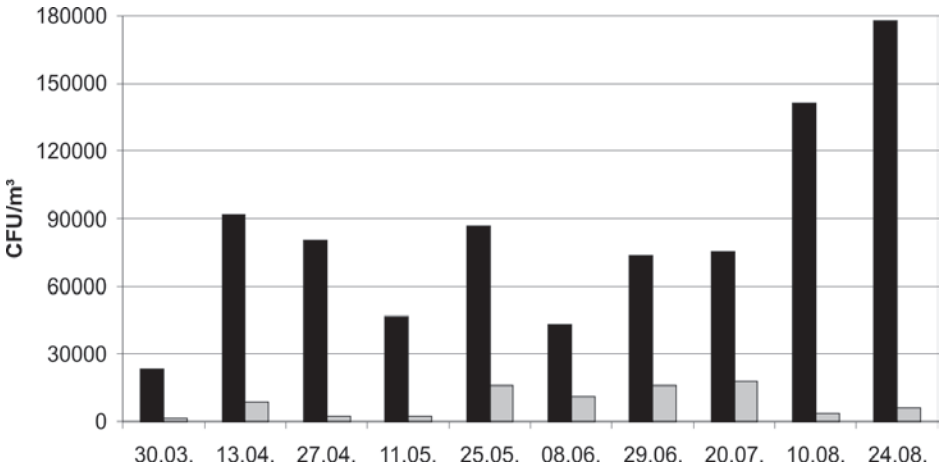

Figure 2. Concentrations of micro-organisms from a piggery with 2000 animals before (■ raw gas) and after (■ clean gas) treatment with a three-stage air scrubber (Hartung et al., 2011).

5. DISCUSSION: The presented data show that viable bacteria including staphylococci when emitted from pig and poultry houses can be distributed by way of the air over distances of several hundred metres downwind where they can reach neighbouring farms or residential areas. Therefore staphylococci may serve as indicator organisms for bio-aerosol emissions at least for broiler barns and can help to estimate "safe distances" between neighbouring farms and between farms and residential areas. Future investigations should take into consideration beside the culturable also the non-culturable staphylococci. Total cell counts measured at sampling sites downwind from barns may contribute to our understanding of the emission amounts; they are less useful to serve as indicators because they can come from other sources.

Conclusions:

1. Bio-aerosols are present in the atmosphere of farm animal houses in considerable amounts and can be harmful for the health of animals and people working in the animal house.

2. These bio-aerosols are emitted by way of the exhaust ventilation air into the environment and concerns are growing that they may have a negative effect on the health of residents living nearby.

3. The travel distances of e.g. *Staphylococcaceae* can be more than 500 m from the farms in prevailing wind directions. MRSA can be emitted similarly from positive farms.

4. There is an urgent need for the development of comprehensive strategies for the qualitative and quantitative measurement of bio-aerosol emissions and the deposition in the vicinity of livestock enterprises.

5. Future work should also focus on the detection of animal species specific "marker" bacteria in order to facilitate discrimination between different farm sources.

6. For regional planning purposes future pollution reduction strategies in livestock production should be enhanced bringing together experiences from practical field measurements and tools like numerical dispersion models in order to define "safe distances" between livestock farms and residential dwellings.

7. Bio-filters and bio-scrubbers can considerably reduce the bacterial load in the exhaust air of piggeries.

8. Reducing air pollutants in animal houses will provide a safer and healthier work environment for employees and a better atmosphere for the animals improving their health, welfare and performance.

9. Reducing emissions will at the same time reduce the risk of transmission of pathogens indoors as well as between neighbouring farms.

10. A future-oriented sustainable farm animal production should enhance also standards to prevent or reduce the spread of pathogens via the air. This meets the overall topics of animal welfare, consumer protection, economy and occupational health.

11. Future research in animal husbandry should promote the development of low pollution animal houses – which can also improve the respiratory health of the animals.

12. Low emission animal houses are probably more effective and less costly than the end-of-pipe techniques which are presently used in form of bioscrubber and biofilters.

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Emissions of Gas and Dust from Livestock

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ABSTRACT

This book provides a compilation of the papers presented at the first International Symposium on EMIssion of gas and dust from LIvestock (EMILI 2012). In regions of intensive livestock production, many countries must cope with environmental impacts due to livestock activities.

These impacts concern all compartments of the environment: water, soil and air. According to national emissions inventories, livestock activities are major contributors of pollutant gas emissions, such as nitrous oxide, methane, ammonia and dusts. For many years, scientific research has focused on quantifying these emissions more accurately, understanding the emitting processes and proposing mitigation strategies.

This symposium was held in 2012 to provide an overview of the state-of-the-art research on these topics. Organized in six parallel sessions, it aimed to communicate up-to-date information on emission factors, emitting processes, mitigation series, modeling, measuring methods and also the environmental evaluation of pig, poultry and cattle production.

RMT élevages & environnement

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