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batfarm

Reconciling livestock management to the environment

Applying Best Available Technique (BAT): from the lab to the farm

European workshop

Rennes, France – 19 & 20 March 2013

Coordinated by
Dr Laurence LOYON - IRSTEA

Proceedings and minutes from the meeting

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24 March 2013

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Summary

Introduction

It is now well established that livestock is responsible for ammonia (NH_3) emissions, greenhouse gas emissions, for nitrate pollution of water resources or for dust emissions: $PM_{2.5,10}$… . There is an urgent need to reduce these emissions:

- In general, to comply with different international protocols (Göteborg, Kyoto,…), with various European legislation (Nitrate Directive, Water Framework Directive, Soil Directive (in preparation), Ceiling Emissions Directive, Welfare Directive, organic farming,…)
- Under IPPC/IED to obtain a permit for operating intensive livestock units (pig and poultry), with an on-going revision of the BREF guidelines

However many questions relating to BAT selection and application are remaining and at present there is no standard tool or document on BAT selection and application (whether IPPC/IED or not). In this context, IRSTEA organized a European Workshop on livestock management (from the housing to the manure spreading) in March 2013. This workshop was organized under the European Interreg Batfarm (www.batfarm.eu) coordinated by Dr Pilar Merino (Neiker, Spain)

The aim of this workshop was to gather scientific researchers and IPPC/IED inspectors in order to exchange ideas on the scientific knowledge on techniques, (Best Available Techniques and others), for the housing, storage, treatment and spreading steps and the technical real application on such techniques.

The main topics discussed covered:

- Scientific knowledge (including a short review on the impact of livestock on the environment (air, water, soil).
- Which pollutants? Level of emissions? Key parameters influencing emissions?
- Techniques available for reducing emissions (including BATs and non-BATs)
- Which technique for which impact (air/soil/water)?
- Ranking of the different environmental impacts
- Methodology to evaluate the efficiency of a given measurement technique

Dr Laurence LOYON
On behalf the Batfarm Project Team

- The 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (http://www.unece.org/env/lrtap/multi_h1.html)
- The Kyoto Protocol to the United Nations Framework Convention on Climate Change (http://unfccc.int/kyoto_protocol/items/2830.php)
- The Nitrates Directives
- http://ec.europa.eu/environment/water/water-nitrates/
- The Water Framework Directive
- http://ec.europa.eu/environment/water/water-framework/
- Other European Directives : http://ec.europa.eu/

List of participants

Aguilar M	INTIA, Spain
Arriaga H	NEIKER, Spain
Audois M	French Ministry of the Environment
Bonmati A	Giro, Catalonia, Spain
Burton C	Consultant, France
De Barmon V	Adjoint Service environnement, France
Doreau M *	INRA, Theix, France
Dourmad J.Y.*	INRA, Saint Gilles, France
Dupard P	Irstea, France
Edouard N	INRA, Rennes, France
Eglin T	Ademe, France
Filby L	SEPA, Scotland, UK
Florean M *	Ministry of Environment and Climate Change, Romania
Grimm E *	KTBL, Germany
Groot Koerkamp P *	Wageningen UR, The Netherlands
Guingand N *	Ifip, France
Guiziou F	Irstea,France
Hassouna M *	INRA, Rennes, France
Holdsworth A *	Environment Agency, UK
Lagadec S	CRAB, France
Lalor S	Teagasc, Ireland
Lanigan G	Teagasc, Ireland
Levasseur P	Ifip , France
Lorinquer E	Idele, France
Loyon L	Irstea, France
Jordana L	Government of Navarra, Spain
Magri A	Irstea, France
Martin E	Citepa, France
Martinez J	Director of Irstea Rennes Centre
Meda B	INRA, Tours, France
Merino M	Neiker, Spain
Misselbrook T *	North Wyke Research, UK
Muldowney J	Department of Agriculture, Food and the Marine, Ireland
Pahl O	CGU, Scotland, UK
Philippe FX *	University of Liège, Belgique
Ponchant P	Itavi, France
Sameiro de Sousa T *	Ministry of Agriculture and Environment, Portugal
Sommer S *	University of Southern Denmark, Denmark
Veldkamp T, *	Wageningen UR, Livestock Research,The Netherlands
Webb J *	Ricardo-AEA, UK

*** Invited speaker**

Tuesday 19th March 2013	
9h-10h	**Introduction**
Welcome	J. Martinez *Director of Irstea Rennes Centre*
Introduction to the workshop	L. Loyon and C. Burton *Irstea & Consultant*
BATFarm Project	P. Merino *Neiker, Spain*
IMPEL Presentation 1	M. Florean *Ministry of Environment and Climate Change, Romania*
10h30-12h45	**Session 1: Nutrition**
Cattle	M. Doreau *INRA, Theix, France*
Poultry	T. Veldkamp *Wageningen UR, NL*
Pig	J.Y. Dourmad *INRA, Saint Gilles, France*
IMPEL Presentation 2	A Holdsworth, *Environment Agency, UK*
Discussion 1	
14h-17h45	**Session 2: Housing**
Cattle	T. Misselbrook *North Wyke Research, UK*
Poultry	P. Groot Koerkamp *Wageningen UR, NL*
Pig	F.X. Philippe *University of Liège, Belgique*
Discussion 2	

Wednesday 20th March 2013	
9h-12h45	**Session 3: storage, treatment, spreading of manure**
Storage	S. Sommer *University of Southern Denmark, Denmark*
Treatment	A. Bonmati *Giro, Spain*
Spreading	J. Webb *AEA, UK*
IMPEL Presentation 3	T. Sameiro de Sousa *Ministry of Agriculture and Environment, Portugal*
Discussion 3	
14h-17h30	**Session 4: How to assess a BAT**
Measurement Techniques of Livestock Gas Emissions	M. Hassouna *Inra, Rennes, France*
Best Available Technique Assessment Tools	E. Grimm *KTBL, Germany*
Guide of BAT in French Livestock Production	N. Guingand *Ifip, France*
Batfarm model	M. Aguilar *INTIA, Spain*
Discussion 4 and Conclusions	

1. Introduction

This document sets out the material used within the European Workshop “Reconciling livestock management to the environment - applying Best Available Technique (BAT): from the lab to the farm” which was held on the 19 and 20th March 2013 at the Mecure Hotel in Rennes, France. The workshop was organized by Mme Laurence Loyon of the research organization IRSTEA (formerly Cemagref) and with the assistance of Dr Colin Burton acting as consultant. The activity was conducted as part of the BATFarm project which is coordinated by Dr Pilar Merino of NEIKER (Spain) and supported by the European Regional Development Fund management by the Atlantic Area Transnational Programme.

The workshop was organized around 12 invited experts with specific knowledge in the technical areas around the current BAT listing applying to the Pig and Poultry sector and as described in the related BREF document (2003 and currently under revision). A further group of three experts working in the area of BAT administration & application were also invited and together with the technical experts formed the main discussion panel. Also present, in addition to the workshop organizers, were members of the BATFarm project and, the meeting being *open*, a wide selection of other interested parties working in the same area – a complete listing of all those participating is given above. The technical material presented in this document is organized as follows:

- Formal minutes (given here) based around the discussion of a series of topics as described by the agenda.
- The presentation of supporting written material provided by the invited speakers which was circulated in draft form prior to the meeting – a final revised version has been compiled and set out in Annexe 1.
- Presentation material during the meeting (as PowerPoint files) is reproduced in Annexe 2 and referred to in the minutes by the code PPx.

The meeting was formerly opened by Dr Jose Martinez (PP1), Regional Manager of Irstea in Rennes, being the research centre acting as host for the workshop. Mme Loyon then proceeded to set out the objectives and structure of the workshop (PP2) which sought a clearer understanding of the application of appropriate and effective BAT technology. Lastly, Dr Burton reminded those present of the responsibility of the scientific community in enabling good policy development by providing clear direction in the technical debate – to that end, he encouraged an active participation in the key discussion sections that followed the presentations.

2. The BATFARM project

Dr Merino (Neiker, Spain) gave an overview of the collaborative project, BATFarm which is now entering its fourth and final year of activity (PP3). In the following discussion, several members of the audience (who are involved in the BREF review process) expressed concern that the outcome of this project needs to be well communicated to the review panel. In addition, there was considerable interest in the software package intended as a specific outcome of this project (see also presentation of the BATfarm software at the end of the workshop, below).

3. Comparison Programme on Permitting and Inspection of IPPC Pig Farming Installations in IMPEL Member Countries

Mme Florean of the Ministry of Environment and Climate Change, Romania presented on an on-going evaluation of IPPC uptake (PP4) including means to improve licensing and inspection of IPPC pig farming installations by developing practical guidance. In the discussion that followed, there was concern that the presented material gave a rather negative image of the application of BAT in the Pig and Poultry sector; this was not denied but rather emphasis needs to be directed to the necessary improvements in the implementation process.

4. Session 1: Nutrition

4.1 Decreasing environmental impacts from cattle through nutrition: what may be the best available techniques?

Dr Doreau (INRA, Theix, France) presented options relating to feed regime modification as a means of reducing negative environmental impacts from the cattle sector (PP5). It was clearly noted that cattle farms currently remain outside of the IPPC licensing scheme but BAT technologies were being pursued to meet national objectives and in anticipation of possible changing European regulations in the future.

4.2 Reduction of ammonia emission from poultry houses by nutritional tools

The application of dietary control within the poultry sector was presented by Dr Veldkamp (Wageningen UR) of the Netherlands (PP6). In this case, some of the ideas discussed are already registered (or being considered) as BAT but in the following discussion, it became clear that national pressures in the Netherlands may be going further than the current European objectives.

4.3 Pig nutrition: impact on N, P, Cu and Zn in pig manure and on emissions of ammonia, greenhouse gases and odours

The situation with respect to pig production was set out by Dr Dourmad (INRA, Saint Gilles, France) in his presentation (PP7). Because of the intensive and enclosed systems often used in both pig and poultry production, some overlap in approach was apparent with respect to the dietary approach (and even more so with respect to building and manure management).

4.4 Discussion relating to the use of animal diet regimes as a means of control

In addition to the three previous presentations, discussion was also initialized by a series of questions presented by the workshop organisers (PP2). The main themes and comments arising were as follows:

- Dietary control is less developed for cattle than for pigs and poultry but this might be changing, especially for animals that are housed all year round (no access to pasture). Noted again that IPPC (as yet) does not apply to cattle but the contribution to emissions (methane, nitrous oxide and carbon dioxide is a large part of the total from the livestock sector: see PP5 – Doreau). Methane emission in particular represents a large energy loss to the animal and thus may of interest in future research.

- There remains some resistance from farmers to any diet changes that don't bring a clear benefit to animal performance. Measures relating to diet modification that are solely for environmental benefit are met with some concern – claims of reduced animal performance being cited.
- Some discussion on the merits of separation of manure (into urine and feces) and the impact of diet on the resulting pH especially – however the relationship between diet and manure composition (with respect to environmental impact) is not clear.
- Of special note is that emissions can also occur during the production of feedstuff – this needs to be included in the overall assessment of a given system.

Table 1*: revised scoring with respect to level of knowledge and application of abatement technologies with respect to each livestock sector (changes in bold)*

Strategy	**Main Impact**	**Knowledge/Application**		
		Pig	Poultry	Cattle
Protein content	Reduction of N-excreted and of NH_3 emissions	++/++	++/++	++/++
Amino acid balance		++/++	++/++	++/+
Multiphase feeding		++/+	++/++	
Dietary electrolyte balance		+/-	+/+	
Additives		+/-	+/-	+/+
Enzymes		++/++	++/++	
Fibrous feedstuffs (fermentable carbohydrates)	Modification of N, C-excreted and NH_3/CH_4 emissions	++/-	++/-	
Phosphorus	Reduction of P-excreted	++/++	++/++	
Lipids	CH_4 decrease			++ /++
Permanent grasslands	C sequestration increase			+ /+

- Diets have been largely optimized in the pig and poultry sectors leaving many of the more recent proposed changes with little perceived benefit (cost neutral or negative): as for other environmental measures, BAT or other, there is the central issue of justification on an economic basis.

- In some instances, the use of additives such as nitrification inhibitors for cattle feeds, raise health concerns such the possible contamination of the milk produced. Other additives such as those promoting feed digestibility may yet be attractive options but they are not fully understood. There are also fears that some additives simply don't work.

- Despite fears over costs, a market for the technologies can bring cost reduction (by competition) and thus changes the cost base. This is also a danger of a MACC curve analysis, as the outcomes can be skewed towards 'current' costs rather than towards more fluid realities of costs and economies for the future.
- Another potential growing factor is that of competition between crop production for animals and that for human consumption with the consequence of animal diets becoming based on lower quality feedstuffs – this in turn overriding to some extent environmental objectives.
- A great deal of work has been published including in the modification of cattle diet – some modification to the summary table given in the introduction (PP2) was proposed by several participants; the revised table is given in Table 1 (above).
- In answer to the question “what items are advanced far enough to be considered as BAT now or in the near future”, two themes were put forward:

    - *Feeding nitrification inhibitors (cattle) – (research being undertaken in Ireland and New Zealand);*
    - *Effect of diet on digestible fraction of manure - impact on methane emissions in subsequent manure storage, and possibly on the N_2O emissions after land application.*

- There was also some discussion on Emission Factors (EF) with respect to the overall evaluation of benefits of diet modification as a BAT technique – evaluation of methods is clearly a key issue (see Session 4 below).

5. Controlling odour on pig farms

Mrs Holdsworth (Lead technical Adviser for Intensive Pig and Poultry farms of the Environment Agency UK) provided a useful review of issues relating to offensive odours (PP8). The impact of odour is considered more of a nuisance yet it has (along with other nuisance factors) been a driving factor in good farm management.

5.1 Discussion

Odour is an important factor within IPPC licensing and (in the UK) it is governed by the Environment Agency in the implementation of the directive. This means only pig and poultry farms covered by IPPC leaving odour complaints relating to numerous smaller farms and all cattle units under the jurisdiction of the local authorities. Measures in the latter case tend to relate mostly to new and expanding farms, determined at planning stage: this may include predictive modeling as part of the authorization. Otherwise, odour remains a poorly understood and implemented factor both within and outside the IPPC scheme and further clarification will be likely.

6 Session 2 : Housing

6.1 Cattle Housing – Emissions and Mitigation

Issues relating to cattle housing were presented by Dr Misselbrook (Rothamsted Research, North Wyke, Okehampton, UK) with again, discussed methods arising from national and other European legislation rather than from the IPPC or IED Directives (PP9).

6.2 Environmental impact of Poultry production - housing

A review of techniques relating to poultry housing was presented by Professor Groot Koerkamp (Wageningen UR, The Netherlands) covering both broiler and egg laying from hens (PP10). As for dietary methods, many of the techniques go beyond current BAT being determined by national legislation to meet specific local problems.

6.3 Emissions of NH_3, N_2O and CH_4 from pig houses: Influencing factors and mitigation techniques

The housing situation with respect to pigs was presented by Dr Philippe (Department of Animal Productions, Faculty of Veterinary Medicine, University of Liege, Belgium). Once again, similarity with the approaches taken with the poultry sector was apparent underlying the benefits of a common approach to similar problems but differences were also clear (PP11).

6.4 Discussion on BAT in the context of animal housing

As for the discussion on feed modification, the session was opened with a series of questions to shape the debate (PP2). It was noted that the set of emissions went beyond the often-cited ammonia and included also nitrous oxide, methane, dusts and odours. Disease transmission could have also been included but this was largely excluded from an already very wide basis of discussion.

Affordability of abatement techniques

Initial remarks quickly focused on economics and the affordability of the specific techniques that are (or will be) listed as BAT. Some are clearly more efficient (and more expensive) than others leading to some need for cost/benefit analysis in terms of pollution abatement units. Some technologies such as air scrubbers can be very efficient (with respect to dusts, ammonia and odours) yet are currently too expensive to be considered BAT: this raised the question why some methods are affordable in some parts of Europe yet not in others? The “regional argument” was put forward suggesting different financial costs across the EU. This might arise, for example, where air conditioning or specific ventilation needs are necessary for maintaining the building environment – some equipment suppliers might then add in air cleaning systems as part of the package. Local incentives (tax benefits or grants) were also cited. More generally, it was noted that few farmers would implement technologies with no apparent benefit unless obliged to do so.

BREF revision

During discussion, it was noted that the new BAT reference document (for the pigs and poultry sector) which was already behind schedule, would need to be finalized this year. The impression was given from those involved in the revision process that there was still an inadequate awareness on the full range of available technologies that may be classified as BAT: the implication was that some methods may be left out due to a lack of information. There was also a lack of information on the relative performance of one BAT compared to alternative BAT's making ranking difficult. As a further consequence of this situation, the option of specifying maximum acceptable emissions (X kg/animal place per year) was being considered; such limits are expected to be lower than current typical emission factors (possibly as low as a third of current emissions) with a significant impact on IPPC registered farms. Furthermore, implementation will then be required within four years. The challenge was thus with scientists and technology experts to be clear with the scope of available abatement methods.

Conflicts between technologies

One common concern arising from the implementation of BAT was from interference effects – ie: solving one problem may cause others elsewhere. Auditing and evaluation of implemented procedures would be made more difficult because of such consequences of given techniques. In relation to this statement, the following remarks were noted:

- A lower ventilation rate in pig houses may be expected to reduce emissions but the local environment will become more highly concentrated in ammonia raising animal welfare problems.
- Deep litter systems can reduce ammonia emissions but at the expense of increased emissions of nitrous oxide?
- Nutrient conservation is often a key strategy: acidification of manure (both liquid and solid) would seem attractive in this context (with respect to ammonia emissions). However, the use of acid may cause corrosion problems and possible present health risks. Nonetheless, the technique is in common use in Denmark.
- Better ventilation can keep poultry litter drier and thus cut ammonia emission – but at the expense of higher dust emissions?
- Building cooling systems can cut emission and improve the environment for animals – this would presumably vary according to region.

General comments

- Frequent removal of solid manure (by scraping) or liquid manure (by flushing) can be expected to reduce building emissions (ammonia, methane and odour). Further measures would be needed during subsequent handling to avoid emissions "downstream" of the buildings.
- Separation of urine and feces in pig buildings is considered BAT if already installed but the technique is not proposed as BAT for new buildings. The reasoning behind this was not clear.

- There was concern that *deep litter* was not seen as a BAT system but rather as an established means of animal production (especially in the organic production sector). As such, it may be a starting point for improvements, but not in itself an optional technology.
- Some discussion on additives for litter or bedding (including nitrification inhibitors) led to a general remark that *only* those methods gaining a large amount of abatement should be considered. This may not have be a generally accepted point as a combination of small improvements may also achieve the same reduction as a single effective technique. However, the discussion did raise again the point of evaluation and validation procedures against a fixed reference point.
- The relative contribution of possible nitrous oxide emissions from buildings (especially those with bedding systems) was a point of dispute. Some participants suggested that the amounts from buildings were minor when compared to the emissions from the field. This view was not shared by others who pointed out that building losses could be of a similar order to those of ammonia (the volatile N source being oxidized from one form to another). *This needs clarification based on the best data from emission inventories*.
- More generally, it was broadly agreed that emissions from none-IPPC farms may well greatly exceed from those included in the licensing scheme – especially when noting the very large number of small farms, many of which would not have resources to allow the implementation of BAT technologies anyway. National legislation was more demanding in some countries suggesting that IPPC licenses represent more often a "*minimum*" level of control. This led to a broader discussion on the definition of farm size – based on a geographical location of buildings, ownership, common operation between units – interpretation across the EU may not be consistent but this aspect probably falls outside the scope of the workshop.

7. Session 3: storage, treatment, spreading of manure

7.1 Ammonia volatilization from manure during storage and after application in the field

The third session was divided into the three principal steps in manure handling: its storage, possible treatment and subsequent land spreading. Dr Sommer (University of Southern Denmark, Denmark) presented on both storage and spreading abatement techniques (PP13) with emphasis on the key role of modeling in the demonstration of a valid technique, BAT or otherwise.

7.2 Manure Processing Activities in Europe - Project reference: ENV.B.1/ETU/2010/0007

The very wide subject area of manure treatment was presented by Dr Bonmati (Giro, Catalonia, Spain) using the results of a recent project carried out to estimate current use of manure treatment technology across the EU (PP14). This project, (carried out in collaboration with Agro-Business-Park, Denmark) covered all technologies that were use including many that are not listed as BAT. A series of four useful output reports can be down-loaded from the website http://agro-technology-atlas.eu/knowledge.aspx.

7.3 Manure spreading - efficacy, agronomic impacts and costs of reduced-NH3 emission manure application methods

Dr Webb (Ricardo-AEA, UK) covered the last stage of manure handling (land-spreading) which represents a crucial step if the benefit of control techniques applied “upstream” is not to be lost (PP15). A wide range of equipment exists some of which can abate emissions of ammonia and/or nitrous oxide – retained nitrogen should not be allowed to lead to nitrate leaching: seasonal timing to correspond to crop needs is equally important to equipment or technology specification.

7.4 Discussion relating to BATS based around livestock manure handling

Discussion was initiated with an open question from the workshop organiser on the main target areas for effective abatement and of the potential value of establishing a maximum emission as a point of reference (to enable evaluation). The latter was based on the established concept of a maximum methane potential from a waste substrate (sometimes referred to as B_0) – is it possible (for example) to establish a maximum ammonia emission for a given farm system and thus to rate farms with BAT against such a reference point? The initial response was that the level of total ammoniacal nitrogen (TAN) in the wastes would be a good indication of potential and that there were standard values available for the levels presents in animal wastes. Comment was also made on organically bound N also present but the mineralization process that releases this fraction was often too slow to significantly increase the TAN pool. A wider discussion on factors influencing emission did not help to tie down a clear reference point but concluded that (i) lab measured values would have a role, (ii) modeling may be a better option with a broader application and (iii) landspreading would be the key area for attention in terms of overall losses.

Land-spreading was a key area of interest for scientists and farmers alike representing the key to “closing the nutrient cycle” and (for the farmer) being an important farm operation. Oddly enough, IPPC permits don’t usually specify land-spreading methods[1] although timing and soil/crop conditions are controlled in many EU countries either by national legislation or under the Nitrate Directive. Nonetheless, good land-spreading that enables benefit from nutrient recovery is a relatively easy concept to sell to farmers and in this respect, BAT and farmer interests can coincide. Techniques involving excessive land compaction from heavy equipment are generally not welcome though (due to soil damage). Furthermore, they may be practical issues such as access for larger equipment that may preclude the implementation of certain land-spreading options.

Another aspect relating to land-spreading and possible BAT is evenness of spread. A splash-plate tanker may (apart from the higher likely emission) also be a poorer choice than injection or trailing hose as it offers a poor nutrient distribution. Some farmers may be reluctant to take advantage of such benefits but environmental obligations in this direction will at least come with some selling points: however, it was noted that not all environmental measures will aid farmers, and in some cases they will have to accept regulatory obligations.

Treatment as a technique can have mixed responses from farmers as it can be costly but with some perceived benefit that may defray the cost. Spreading aerobically or anaerobically-treated manure may improve nutrient uptake via the principle of reduced viscosity and faster soil penetration (implied by research results from Denmark). It was noted thought that this would only be the case if

[1] *This is because exporting manure to 3rd parties is out of the scope and control of the permit. It is common practice on poultry farms due to bio-security restrictions*

good spreading practice was also observed – an important example of the need for consistent implementation of regulations if one action is not to be negated by the absence of a second.

Manure treatment more generally is not wide-spread other than those basic operations linked to general manure handling and storage (eg: separation). There has been some regional uptake of advanced biological technologies (eg; aerobic treatment in Brittany and AD in Germany – PP14) but often local factors are involved and use of such technology is patchy. AD clearly can be motivated by other factors such as energy production and its environmental credentials may be questioned although it can reduced methane emissions and offensive odour. The option of centralized treatment might be expected to make such technology accessible to farmers (especially smaller units) but transport logistics can be a limiting factor. Nonetheless schemes exist in Holland, Germany, Denmark and Spain with additional benefits of local employment and improvement nutrient use.

Even with well-organized schemes, treatment running costs seem excessive rising to as much as 30 euro/m^3 of treated manure; then there are also the installation costs at the beginning. The value of the manure can defray this expense but cattle manure (as an example) would be no more than 6.50 euro/m^3. Thus the observation arose that some methods may always be too expensive to allow an economically competitive farming operation. The “regional factor” again came into discussion with a simple observation that treatment would be pursued if the alternative costs (such as transport out of the region) were even more costly. Finally, it was noted that the existing BREF lists few treatment options as BAT and that treatment would probably always remain an option limited to specific farms with special problems.

8. Best Available Techniques in five key environmental issues

In the third of a series of supplementary presentations relating to the IMPEL network, Dr Sameiro de Sousa (Ministry of Agriculture and Environment, Portugal) set out five key areas for BAT implementation (PP12). This arose from the Comparison Programme on Permitting and Inspection of IPPC Pig Farming Installations in IMPEL Member Countries. The areas are listed as (i) Manure Storage; (ii) Manure spreading on land; (iii) Animal housing systems; (iv) Air abatement techniques and (v) Odour assessment and reflect the structure of the workshop as organized.

8.1 Discussion

The presentation led to a broad discussion on the implementation of IPPC, questions were mostly based on requests for information or clarification. One query was the need for a BAT technology if (for example) ammonia was shown not to be a local problem. The reply from Dr Sameiro de Sousa suggested that a great deal depended on the judgment of the national “permitting authority” in the light of technical evidence. The issue of conflict between EU policies also arose with farmers in Brittany (for example) concentrating more on meeting the Nitrates Directive than the IED (IPPC) Directive. A further question related to responsibilities with respect to BAT implementation – it was noted that it was the farmer who sought the license but on a technical level, consultants and experts would be the key people in specifying effective technologies. This last point brought discussion back to the validation question and concerns over the [apparent] lack of precise data that could rank the various options. Discussion then concluded with the issue of setting emission limits as a future tool for implementation – this raised some confusion on the various terms used AEL (associated emission limit – emission of X as per animal place per year), BAT-AEL (the same referring to a BAT technique), ELV (emission limit value), APL (associated performance level - % reduction when compared to a reference system). As well as highlighting the need for a glossary with clear definitions, these final remarks also raised again the question on how systems are evaluated in a fair, valid and consistent way.

9. Session 4: How to assess a BAT

9.1 Measuring gaseous emissions from animal houses and storage facilities

The final session in many ways was the most challenging as evaluation (in all senses of the word) is the key to the whole strategy of BAT. The first aspect of this process (measurement) was discussed by Dr Hassouna (INRA, Rennes, France) in the context of emissions from housing and manure stores (PP16). The establishment of standard acceptable methods would appear to be as important as the BAT itself.

9.2 BAT assessment tools and VERA test protocols

The evaluation of an abatement procedure with the intention of ascribing it BAT status (or not) was the content of the presentation by Dr Grimm (KTBL, Germany) (PP17). Several procedures were described including those emerging from regional initiatives such as VERA (Verification of Environmental Technologies for Agricultural Production) currently including Germany, The Netherlands and Denmark.

9.3 A guide on Good Environmental Practices for Breeding (Translation from French)

The third aspect of the evaluation process, communication, was covered by the presentation by Dr Guingand (IFIP, Rennes, France) (PP18). This featured a recently produced guide that set out the main abatement techniques in a logical and straightforward way. The publication was aimed at the end user but still conveys methods in making a complicated subject understandable. Currently only available in French, an electronic version is available at www.rmtelevagesenvironnement.org

9.4 Discussion on methods to evaluate possible BAT techniques

The discussion relating to evaluation methods was lively and confirmed the importance of progressing in this area to move towards established and accepted standards. The debate was quickly animated by the relatively high errors proposed in conjunction with emission measurement. These were cited as ±20% (good) and ±50% (typical) which raised the inevitable question of whether techniques enabling small reductions in emission could ever be verified. As a point of clarification, the common use of the word “uncertainty” was considered to be equivalent to “error” when used in the context of measurement. The breakdown of measurement error was attributed to (i) operator, (ii), equipment, (iii) procedure and sampling point, (iv) extrapolation / interpolation techniques and (v) system variation. The last factor is of course the simple reality that the emission being measured varies over time – both short term (minutes), medium (days) and long (seasonal).

In response to the challenge of measurement error, options proposed included (i) laboratory measurements, (ii) before/after comparative measurements, (iii) comparison to reference farms and (iv), use of modeling techniques. The concern with laboratory techniques (using defined conditions) is that a real farm situation could be very different – both sets of measurements would always be required with some understanding of scale-up. Comparative methods are attractive as certain common errors can thus be eliminated but large differences can still exist and such concepts as a "standard farm" are far from being agreed. The problem may be further complicated by the use of technology with more than one objective and thus not optimized or correctly used for all. For example, a biofilter set up primarily for odour control may also reduce ammonia emissions but below the expected efficiency – would it be considered BAT for both?

With respect to standard measurement methods, it was noted that various publications do exist (eg: those relating to the Gothenburg protocol for example). However, for the most part, much of this information is not easily used being very extensive in quantity yet not well summarized.

The question of discernment of small changes in emission raised concern that those techniques offering modest improvements should not be discarded for the lack of adequate verification. This still raised the question of whether "unproven" techniques should be listed as BAT. The idea remains that a group of minor improvements may yet add up to an acceptable abatement but there would need to be a target to compare this to. It was noted that relative targets (ie: those that require an overall reduction of X%) would be more easily met by poorly managed farms than those already observing best practice. This brings the debate back to the idea of setting absolute emissions (per livestock unit for example) which may not reflect the differing situations between different farm systems or regions of Europe.

Much of the discussion on emissions was clearly focused on ammonia that is at least relatively easily measured (eg: acid traps, IR, GC etc). The situation for the other gases (especially nitrous oxide and methane) is more complicated as concentrations are lower and analytical techniques more expensive. For both gases, GC is the main technique with collection by bags (for buildings) or sampling chamber (for field emission) often used to enable mean figures over a period of time. It was noted that these gases seem to feature less in the BREF documents (than ammonia) even though agriculture is a major source and that both have a large and detrimental effect on the environment. Difficulty in representative sampling, measurement and BAT method validation is likely to be a factor. Evaluation in terms of reducing emissions of other emissions (dusts, odours and pathogenic material) was not discussed beyond the information presented on PowerPoint during the workshop.

10. The BATfarm (simulation) model: a support tool in the selection of environmental strategies in livestock operations in the Atlantic Region

In the final presentation, Mlle Aguilar (INTIA, Spain) presented an overview of a farm simulation model developed as part of the BATfarm collaborative project (PP19). The software remains to be finalized in a coded form but a test-bench version has been run as an extended Excel application. Examples were given of the use of the model to predict the benefits (or other effects) of applying one or more BAT technologies at a defined farm scenario. The final version, expected in the autumn will be freely available via download.

10.1 Discussion

The demonstration of the software package raised considerable interest amongst those present with several questions/comments on its scope and reliability. In answer to such comments, it was made clear that the package would draw greatly on standard emission values but allowing the user to input better data if available. The approach, based on comparison of farm systems (with and without BAT), would ensure that many of the common errors in farm evaluation would not greatly impact on the results. Improvements would always be possible but as a guidance tool, it would be a good first step. It was noted that predictions relating to pathogen risk were general (based on a broad scale of scoring) and that for detailed microbiology concerning specific bacteria, additional study would be necessary.

11. Conclusions – the next steps

During the course of the meeting, a number of possible initiatives were discussed; these are listed below along with the main outcomes from the meeting.

11.1 Publication of workshop proceedings

It was fully anticipated that a full set of minutes would be produced to ensure a good record of the meeting. In addition, a compiled version of this document along with its annexes will be posted on the RAMIRAN website to ensure the maximum dissemination. In addition, the option to publish the discussion as a scientific paper will be explored based on the level of interest arising (possible as 2 parts with a second paper covering submitted material). Initially, coordination will lie with Irestea and L Loyon.

11.2 Possible funded project on a guide for farm evaluation and BAT identification

The growing need for a comprehensive guide is generally recognized that would aid in the evaluation of a farm/region and the association of appropriate BAT's reflecting local factors. Most likely taking the form of a reference book, the idea is to bring together a methodology in farm/region definition, a complete listing of BAT's that may be applied and a subsequent evaluation and verification procedure based on standard procedures. Such an initiative would be largely one of bringing together techniques and information already in existence but often dispersed across a range of sources. Several participants confirmed their interest but others drew attention to similar initiatives already in progress (or being drafted). The first tentative steps of such a project will follow the establishment of an adequate pool of interest amongst participants of the currently reported workshop. Participants were invited to inform the workshops organizers (by email) of their interest and of other similar work in progress that should be taken into account in the drafting of an outline.

11.3 Final remarks

This workshop enabled an open and frank discussion on many of the technical aspects of BAT techniques and their implementation which forms the cornerstone of the IPPC licensing scheme. To a large extent, it allowed the bringing together of a large amount of information and the clear indication that a great deal more scientific material is currently available. There was a feeling that there is a good resource of data covering many of the aspects but that this (for the most part) remains dispersed and only available to a very determined researcher with time to pursue the many lines of literature search that are open. In other words, many of the answers may already exist, but there is a lack of sound and comprehensive review publications that would enable sound decisions. The expression easily fits: "*too much and too little information at the same time*".

Of course, there are some gaps in the detailed knowledge of existing and new BAT technologies but much of this concerns their efficacy and, relating to this, there evaluation. This last point was indeed the most common point of discussion throughout the workshop – how to ensure a fair and efficiency implementation of the scheme across Europe – which comes down as much as a strategy question as one of the development of a valid and fair scheme. The idea of best available measurement (BAM?!) is one aspect of this challenge. Implementing IPPC licensing and the obligation on such listed farmers across Europe to install BAT technologies without a consistent and valid evaluation scheme would seem to be destined for further debate and controversy until adequate and accepted evaluation is agreed.

In conclusion, the workshop has probably only underlined the issues that are already well recognized and already high up in the related discussion across the EU. However, it can be a starting point of a constructive debate and a progressive set of actions amongst the key players, many being present, to tackle this important environmental challenge. The next steps (as described above) will be vital if this initiative is not to be lost.

Annexe1 : preparation material submitted by participants

As part of the preparation requested ahead of the workshop, participants were invited to prepare submissions based on the outline of the workshop as set out below:

Information was requested based on (i) of participant's general expertise and (ii) of country/region of activity. As a guideline, the following headings/questions were set out.

Scientific knowledge

- Resume on the impact of livestock on the environment (with respect to the air, water and soil).
- Which pollutants are of particular concern and why?
- Range of emissions relating to; air, water and soil.
- What EF (emission factors) are used or cited; what units are used in research or for the inventory and/or for declaration data?
- What are the 3 key parameters influencing cited emissions?
- Participant's view on the agreement on livestock BAT Reference techniques to evaluate/compare new techniques enabling emission reduction (taking into account regional variation on EU climate/landform with respect to different levels of emission).

Techniques of emission reduction available (whether BAT listed or not)

- Which technique would you propose for which impact (air/soil/water)?
- Is it posible to rank the different environmental impacts? (e.g.; quantity of NH_3 emissions against NO_3^- emissions?)
- What is the level of knowledge of a given technique on the different impacts?
- What is the level of applicability of those techniques experienced (e.g.: those already used by farmer, only tested at the laboratory scale, or under scientific development)?
- What is the best unit(s) to evaluate the efficiency of a given technique (e.g.: in terms of %-reduction in N, absolute emission $kgN.m^{-2}.d^{-1}$…)?
- Which parameters should be considered/measured in order to assess an abatement technique?
- What is level of precision (with respect to the reduction allocated to a given technique) that we can reliably expect (e.g.: 50% reduction)?
- How can we control the efficiency of a BAT technique applied at the farm level? (e.g.: Vera protocol or new EU ETV)?
- Which method of emission measurement should be used for which technique?
- What is the best way to show the reduction achieved by using a BAT technique? (level of reduction, cost, technical applicability, …)

List of contributions received

1. Processing technology as a tool to a sustainable manure management – August Bonmatí, Michele Laureni, Jordi Palatsi, Xavier Flotats (Catalonia, Spain).

2. Decreasing environmental impacts from cattle through nutrition: what may be the best available techniques? – Michel Doreau, Philippe Faverdin, Katja Klumpp (France).

3. Pig nutrition: impact on nitrogen, phosphorus, Cu and Zn in pig manure and on emissions of ammonia, greenhouse gas and odours – Jean-Yves Dourmad, Florence Garcia-Launay Agnes Narcy (France).

4. IMPEL Projects 2009-2012 – Manuela Florean: Ministry of Environment and Climate Change- National Environmental Guard Hunedoara

5. The impact of livestock on the environment and technical solutions available in Germany – Ewald Grimm, KTBL (Germany).

6. Gas Emissions Measurement Techniques for Livestock Building and Storage Facilities – Mélynda Hassouna and Paul Robin (France).

7. The impact of livestock on the environment and technical solutions available in the United Kingdom – Jim Webb (United Kingdom).

8. Cattle housing – Tom Misselbrook (United Kingdom).

9. Emissions of ammonia, nitrous oxide and methane from pig houses: Influencing factors and mitigation techniques – François-Xavier Philippe, Baudouin Nicks (Belgium).

10. Ammonia volatilization from manure during storage and after application in the field – Sven G. Sommer (Denmark)

11. Reduction of ammonia emission from poultry houses by nutritional tools – Teun Veldkamp (The Netherlands).

12. A guide on good environmental practices for breeding – Nadine Guingand (France).

1. Processing technology as a tool to a sustainable manure management

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The contribution paper is organized in two sections. Section one enumerates livestock manure emissions to the environment and its subsequent impacts. In the second section, the most usual processing techniques and their implication on emission abatement and impact reduction are briefly discussed.

Impacts of livestock on the environment

Intensive livestock production, and pig breeding in particular, have experienced a rapid growth in the last few decades, especially concentrating in certain geographical areas. The improper management of livestock manure causes severe environmental impacts related to eutrophication, acidification, release of greenhouse gases, pollution due to toxic chemicals (heavy metals, antibiotics, hormones, etc.) and the use of non-renewable energies (Laureni et al. 2013).
The main emissions due to manure management and its associate impacts are described below:

Nitrogen (*NH_3, N_2O and NO_3^-*)

Based on Smil (1999) estimations, about 170 Tg of nitrogen entered globally in the crop production system. Fertilizers supplied around 50% of these inputs (75-80 Tg N) while biological N-fixation (25-41 Tg N), atmospheric deposition and irrigation waters (21-27 Tg N), animal manures (16-20 Tg N) and crop residues recycling (12-20 Tg N) accounted for the rest. Of this nitrogen, only half was recovered in crop biomass, being the rest either lost to the atmosphere (~25%) and to aquatic systems (~20%) or accumulated into agricultural soils (~2-5%) (Galloway et al., 2003; Smil, 1999).

Ammonia (NH_3) emissions to atmosphere have been reported to be up to 30% of the total N applied. Ammonia is characterized by a short atmospheric lifetime (less that 5 days) and between 20-40% of it is deposited near the source (less than 5 km) (Aneja et al. 2001), provoking different impacts namely soil acidification, water eutrophication, and acid precipitation among others. Globally, annual ammonia deposition was estimated in 56 Mg N/year (Aneja et al., 2001). Furthermore, once converted to NH_4^+ it rapidly reacts with acid substances, mainly sulphuric, nitric, nitrous and hydrochloridric acids, resulting in the formation of secondary fine particulate matter (aerosols) $PM_{2.5}$ (Rodhe et al., 2005).

Nitrous oxide (N_2O) emissions to the atmosphere from livestock manure are reported to be 3.7 Tg each year. N_2O emissions are mainly associated with storage and land application, being about 0.5-2.0% of the initially applied N (Smil, 2002). Nitrous oxide, being almost inert in the troposphere, with a lifetime of about 114 years, is characterized by a global warming potential (GWP), per mass unit, 310 times higher than CO_2.

Nitrate (NO_3^-) leaching from livestock manure and N-fertilizers represent the primary source of nitrogen in the surface and ground water. This issue has been tackled since long time ago as the impact on human health, namely methemoglobinemia or "blue baby" disease and the presence N-nitrous compound with carcinogenic effect are well documented. The best strategy to face this issue, apart from reducing the production of livestock manure, is the implementation of correct crop fertilization practises in order to optimise its fertilizer efficiency and minimise nitrate leaching to water.

Methane (CH_4) and other emissions

Livestock manure has been estimated to contribute with 17.5 Tg methane (CH_4) and 3.7 Tg nitrous oxide (N_2O) to the atmosphere each year (Steinfeld et al. 2006), corresponding to 26–30 % of non-CO_2 greenhouse gas (GHG) emissions from agriculture (Smith et al. 2007). The magnitude of CH_4, as well as N_2O, emissions differs between livestock categories; pigs are mostly produced in confined systems where manure is handled in liquid form (as a slurry) and stored prior to use, therefore high CH_4 and N_2O emissions can be expected (Petersent et al., 2013). Besides CH_4, N_2O and NH_3, slurry stores are a source of **odour emissions** that can be a nuisance to neighbouring settlements (Schiffman 1998). The most important odorants include volatile **sulphur-containing compounds, indoles and phenols** (Blanes-Vidal et al. 2009; Eriksen et al. 2010; Hansen et al. 2012, Laureni et al. 2013).

Phosphorus and heavy metals

Accumulation of **phosphorous** in soil is an emerging issue in the UE that raises new challenges to manure management. On one hand it is a scarce resource that should be correctly used and recovered from manures in order to avoid leaching to surface water and the subsequent eutrophication phenomena. On the other hand, its accumulation into soil, depending on soil characteristics, seems to have no adverse effects on crops and soils. Apart from the aforementioned environment issues, the interest on phosphorus is growing because it represents a geostrategic issue since the EU has no phosphorus reservoirs.

Livestock manures, and pig slurry in particular, use to contain significant amounts of certain heavy metals, specifically **Cu and Zn** because they are used as feed additives. Continuous application of manures to crop land can lead to the accumulations of those heavy metals. Concentration in soil should be maintained below the level that assures the non transference to the food chain. In this sense the EU has established the maximum concentration in livestock feeds (Directive 85/520/ECC, Regulation Nº 1334/2003). Nevertheless, further work is required to effectively control the presence of heavy metals in feeds and manures.

Pathogens and other diseases

The use of livestock manure as fertiliser must pose minimal risk of transmitting bacteria, viruses, intestinal parasites, weed and crop seeds and crop diseases.
Strict sanitation requirements have been implemented in some countries, aiming to break the chain of pathogens and animal and plant diseases transmission. Denmark was a pioneer country in this area, implementing sanitation measures and veterinary safety regulations as long ago as 1989. Later on, other countries including Sweden, Germany and the United Kingdom have introduced similar regulations. (Al Seadi and Lukehurst, 2012)

Indirect emissions (CO_2 from fertilizers production)

Tenkorang et al. (2009) projected global fertilizers nutrient consumption to increase from 154 Tg to 223 Tg between 2005 and 2030. On the other side, up to about 2-3% of the global energy consumption is ascribed to the energy intensive fertilizers production process with nitrogen fertilizers accounting for about 70% (Ramírez and Worrel, 2006). Direct energy requirements for the production of one Mg of ammonia are between 40-45 GJ (Ahlgren et al., 2008). Thus, the substitution of N-fertilizers can avoid the depletion of fossil fuels and reduce the emission of CO_2 or, in other words, the inaccurate use of manure as fertilizer promote the increasing use of fertilizer and therefore the emission of CO_2.

Processing techniques available for reducing emissions

A processing strategy can be defined as a unitary process or a combination of various unitary processes leading to the fulfilment of a given objective. Such objective must be determined for every farm or group of farms depending on the local constrains and opportunities. The main objective of a processing strategy use to be the improvement of manure management based on nutrient management, but nowadays other objectives are gaining importance: reduction of emissions to the atmosphere (GHG, odours, NH_3, etc.), production of energy, removal of xenobiotic compounds, removal of pathogens, etc. There is not a unique technological strategy suitable for all situations, and there is not a process capable of removing manure.

In this section the most common processing technologies are listed; main objective, the avoided emissions, as well as the risk of emission of the processing technology itself, and the need of further research are summarized. This information has been mostly obtained from *Manure processing technologies. Technical Report No. II concerning "Manure Processing Activities in Europe" authored by Flotats, Xavier, Henning Lyngsø Foged, August Bonmati Blasi, Jordi Palatsi, Albert Magri and Karl Martin Schelde (2011)*

Processing technology	Objective	Benefits and/or avoided emissions	Associate emissions /side effects	Issues that need further research
Solid/liquid separation	Separation of solids from a (semi)liquid stream in two different fractions, one solid and the other liquid	• Solid fractions can be more easily exported to areas with low livestock density, reducing problems derived from nutrient surplus: **phosphorus accumulation and nitrate leaching to water**	• Performance of some systems implies a high exposition of manure/slurry to atmosphere, and thus, risk of gaseous emissions of **COV** and **odours**, as well as **NH_3** • Indirect CO_2 emissions due to electric energy consumption	• Efficiencies and solid phase characteristics depending on the manure type and equipment used. • Quantification of the uncontrolled emissions
Acidification	Lower the level of pH in the manure, and thereby increase the concentration of ammonium (NH_4^+-N) at the expense of ammonia (NH_3).	• Reduction of **Ammonia (NH_3)** emission. • Possible reduction of **CH_4 emissions**	• Emissions of **VOC** and **odours** resulted from the oxidation reaction due to the addition of a strong acid.	• Quantification of the reduction of CH_4 emissions during storage • Odour emissions quantification • Implication on slurry fertilization efficiency
pH increasing –liming-	To stabilize manure and reduce the contents on pathogens. Liming is also applied to increase the pH in view of the application of other processing technology such as N-stripping or nutrient precipitation.	• Indirectly, when used as a conditioning process before P-recovery by precipitation or N-recovery by stripping, the obtained products can enhance the capability of manure/slurry management, reducing problems derived from nutrient surplus: **phosphorus accumulation and nitrate leaching to water**	• If is not well controlled, it may result in an undesired volatilization of **ammonia.**	
Anaerobic Digestion	To produce renewable energy (bio-methane) via biological degradation of organic matter. Mineralization and stabilization of the organic matter are also two important secondary objectives	• Contributes positively to the reduction of greenhouse gas emissions in two ways: decreasing natural emissions to the atmosphere of **methane (CH_4)** and decreasing fossil fuels consumption if this is substituted by biogas **(indirect CO_2 emissions**) . • A number of **odourous** compounds in the slurry are broken down in the anaerobic process, but others are formed in their place. Nevertheless, there is a marked reduction of odour • Anaerobic digestion does not change the overall N/P ratio, and it has only effect on the **N availability** (mineralization). However, digestate is more homogenous, making it easier to reach into the crop root area, enabling **better nutrient uptake** from field crop • **Pathogen reduction** and hygienization (higher in thermophilic range).	• Uncontrolled **leakages of biogas** (from the anchoring points of the gasometers, biogas conductions, etc.) can lead to important emissions of **CH_4**, and other biogas components (**NH_3, H_2S, etc.**) • Digestate storage can also be a source of emissions (**CH_4, H_2S, NH_3, N_2O)**	• Development of protocols and equipments to control biogas leakages • Digested fertiliser properties (long term field experiments) • NH_3 emissions and NO_3 leaching depending on soil characteristics, climate, etc.

Processing technology	Objective	Benefits and/or avoided emissions	Associate emissions /side effects	Issues that need further research
Composting	To obtain a stable product with low moisture content and most of the initial nutrients, free of pathogens and seeds, called compost.	• The significant reduction of mass (water evaporation) reduces substantially transport costs, and reduces **CO_2** emissions • Production of organic fertilizer that improves fertilization practises and soil characteristics (structure) • **Pathogens** and seeds removal • **Odour** abatement	• Emissions of NH_3, COVs and CH_4 during process operation • Direct CO_2 emission (machinery that uses diesel fuel) and indirect CO_2 emissions due to electric energy consumption	• Mixtures and process operation parameters to reduce emissions • Development of efficient control devices to minimise gaseous emissions (biofilters, scrubbers, etc.) • Development of online control algorithms to optimise oxygen uptake and reduce energy consumption.
Thermal drying	To obtain a dried product from manure/slurry (solid fraction, raw or digested) with most of the nutrients, easier and cheaper to transport and land spreading (if pelletizing is applied).	• Production of a dried product easily to handle, with moderate-high concentration of nutrient (N and P) • Organic matter sanitation, **pathogens and seeds removal**.	• Potential risk **of ammonia (NH_3)** and **organic volatiles (VOC)** emissions. Previous nitrification-denitrification, acidification or anaerobic digestion process is required • **Cu, Zn** and other heavy metals are present in the dried product (depending of their concentration in the raw manures). This fact could limit their use on field crops, • Need of special machinery for land spreading if pelletizing is not applied (dust product)	
Combustion	Transformation of organic materials into energy by thermal oxidative process, resulting in a substantial reduction of volume and mass. Thermal energy should be recovered and it is usually transformed into electricity.	• Sanitation and destruction of **pathogens** and also **pharmaceutically activated compounds.** • High reduction of volume and mass of manure/slurry, • **P** can be reused for crop fertilization if appropriate processing of the ashes is done	• Potential risk of emissions of. **NOx, SOx, H_2S, HCl, dioxins, etc.**	• Fertilizer value of the produced ashes • Further processing to increase nutrient bioavailability or toxicity
Membrane filtration (MF, UF, RO)	Microfiltration (MF) is a low-pressure cross-flow membrane process for separating colloidal and suspended particles in the range of 0.03-10 µm. Ultra filtration (UF) concentrates suspended solids and solutes in the range of 0.01—0.1 µm. And reverse osmosis (RO) removes small dissolved molecules below 0.0001 µm.	• As regards leaching of **N and P, it can have a positive effect**, assumed that the products of the process (fibre fraction, concentrate and permeate) are being used in the most optimal way; field crops can be fertilized with more precision according to their demands. • Sanitation and retention of **pathogens.**	• Indirect **CO_2** emissions due to high electric energy consumption	• Fertilizer characteristics of the concentrate obtained

Processing technology	Objective	Benefits and/or avoided emissions	Associate emissions /side effects	Issues that need further research
Concentration by vacuum evaporation	The objective of the vacuum evaporation is to concentrate nutrients and organic matter evaporating water at temperatures lower than 100ºC and pressure conditions below vapour pressure of the liquid, recovering the water and volatile emissions in a further condensation step.	• Slurry/manure volume reduction (reducing transport costs and **CO_2 emissions**) and nutrient recovery (**N, P and K** in concentrate fraction). • The concentrate (where N is contained) is also **hygienized** (according to the operation time/temperature).	• No negative effects, since evaporated flow is recovered as a condensate**.** Theoretical **"0 gas emissions"** including odours • **Heavy metals** are concentrated in the concentrate stream that can limit product application or land spreading. • Direct or indirect CO_2 emissions depending on the energy source used	
Ammonia stripping and absorption	Removal of ammonia through volatilization from a liquid phase, by means of a gaseous counterflow (air or steam) and its subsequent recovery in an acidic solution as ammonium salt or by condensation.	• Less nitrogen content in slurries that facilitate their management, • Reduction of **potential nutrients overloads** to the fields and consequent environmental impacts • **Odour** reductions after slurries spreading on the fields, • **Recovery of a valuable nutrient** (nitrogen). • Less external fertilizer requirements (**indirect CO_2** emissions reduction), • ,Volume reduction and consequent less transportation emissions (**CO_2 reduction)**,	• Energy consumption (can be reduced if combined with biogas production): **indirect CO_2 emission**. • Chemicals reagent required, .	• The effect o organic matter slurry characteristics on process efficiency • Characteristics of the ammonia salts obtained • Ammonia stripping process combined with biogas cleaning
Nitrification-denitrification	Biological conversion of ammonium into di-nitrogen gas (N_2) using classical N-removal process, combining autotrophic nitrification under aeration and heterotrophic denitrification under anoxic conditions and presence of organic-C.	• Removal of **ammonia** in form of N_2 (innocuous) gas. The N removal can enhance the capability of manure/slurry management. • Emissions of greenhouse gases (**CH_4 and N_2O**) and ammonia (**NH_3**) are reduced when the biological treatment is compared to the use of storage alone (based on 6 months storage before spreading) • Removal of biodegradable organic matter	• Risk of emission **of N_2O** may exist if process is not well managed. • A higher quantity of sludge is produced (from microbial activity) that should be properly managed. • **Indirect CO_2** emissions due to electric energy consumption •	• Operational strategies to reduce the consumption of oxygen (NDN via nitrite, etc.) and/or organic matter (Anamox process) • Development of online control algorithms to optimise oxygen uptake and reduce energy consumption. • Development of protocols to control N_2O and operational strategies to minimise its emission.
Struvite (and other salts) precipitation	Recover nitrogen and/or phosphorous from liquid manure/slurry in the form of amorphous magnesium nitrogen-phosphate salt called struvite ($MgNH_4PO_4.6H_2O$) or other salts as apatites.	• Possibility of simultaneous **nutrient recovery (N and P).** • Since struvite contains both ammonia and P, it can be used directly as a fertiliser • Nutrient concentration on the obtained salts can enhance the capability of manure/slurry management.	• In highly agitated reactors, or when aeration is introduced for pH increase (CO_2 stripping) it exist the risk of **ammonia and VOC** volatilization • Use of chemical reagents to rise the pH and/or balance the molar ratio of N/P/Mg (in the case of struvite)	• Quality of the obtained salts with regards to nutrient composition and presence of organic matter and other contaminants (heavy metals, etc.) • Strategies to minimise chemical reagents requirements

Processing technology	Objective	Benefits and/or avoided emissions	Associate emissions /side effects	Issues that need further research
Algae production on liquid manure substrate	Nutrients, or other pollutants, uptake by the biomass and their removal from the system through harvesting. Harvested material may be processed into a valuable product.	• **Nutrient recovery (C, N, P** and other nutrients) • Nutrient concentration that can enhance the capability of manure/slurry management. • Recovered biomass presents a very wide range of application, going from biofertilizer to substrate for biogas • **CO_2** fixation	• High footprint (high surface requirement)	• New applications of the recovered biomass and optimization of the existing ones (co-substrate for biogas production, etc.) • Optimization of photobioreactors to improve conversion efficiency • Research of algae species with higher capabilities to use nutrients from residual streams and fix CO_2
Constructed wetlands	Removal of the nutrients, or other pollutants, by means of biomass (plants and microorganisms) uptake and removal from the system through harvesting and denitrification.	• **Nutrient recovery (C, N, P** and other nutrients).. • Nutrient concentration that can enhance the capability of manure/slurry management. • Recovered biomass presents a very wide range of application, • **CO_2** fixation	• Risk of **N_2O** emission, since the nitrification and denitrification process are not controlled • High footprint (high surface requirement)	• Minimize surface requirements by increasing the efficiency of the system

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2. Decreasing environmental impacts from cattle through nutrition: what may be the best available techniques?

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Environmental impacts attributed to livestock have various origins; they can be due to animal physiology, through direct emission of pollutants, to upstream processes (feed production) or downstream processes (manure). Life cycle assessments from cradle to farm gate show that more than 50% of greenhouse gases (GHG) emissions, expressed in carbon dioxide (CO_2)-eq, are due to enteric methane (CH_4) in dairy and beef cattle systems (e.g. Nguyen et al., 2012). Although of lower extent for other environmental impacts, the role of animal physiology and nutrition is one of the key factors which control emission of pollutants.

Defining the best available techniques for mitigating environmental impacts is a major challenge. These techniques must have a proven effect, which often requires a change in practices (and not “business as usual” even if it has a mitigating effect) within the same production system, and should be implemented from now on. In addition, interactions between techniques and, in the case of GHG, between the different GHG (i.e. CH_4, nitrous oxide (N_2O), CO_2) for each of them, should not reduce the mitigating effect. This paper will be focused on GHG net emissions, taking into account carbon sequestration in soils, and on pollutants related to N losses by animals. Nutritional strategies and management changes, especially for grassland use, will be considered.

Mitigating enteric methane production

Methane is produced in the rumen by carbohydrate fermentation. Starch and cellulose are degraded by a consortium of microbes, mainly bacteria and protozoa, and produce hydrogen together with volatile fatty acids (VFA). Hydrogen is converted into CH_4 by archaea methanogens; most methane is eructated. Methane production is thus positively related to fermentable carbohydrate intake. Among VFA, acetate and butyrate production releases hydrogen whereas propionate production takes up hydrogen, so that concentrate diets, which increase propionate proportion in VFA, produce less CH_4 than forage diets. The replacement of carbohydrates by lipids allows reducing CH_4 because lipids are not hydrogen producers in the rumen. Different additives or biotechnologies have been tested for CH_4 mitigation; their mode of action may be one or several of the following: i) reducing hydrogen production; ii) reducing archaea methanogens; shifting VFA towards propionate; iv) utilizing hydrogen in other pathways than CH_4 production (Morgavi et al., 2011). In addition, when dry matter intake (DMI) increases, CH_4 produced per kg DMI decreases due to lower retention time of nutrients in the rumen. Methane expressed per kg of product, milk or meat, decreases when animal level of production (milk yield, liveweight gain) increases, because their level of intake is higher, and because the ratio between the percentage of feed used for production *vs.* maintenance increases.

Among numerous available techniques to mitigate CH_4 emissions, few can be considered to be implemented at large scale. The increase in genetic merit is a constant trend for many years, and has become “business as usual” technique. The genetic improvement of productive efficiency is a stimulating way of progress, but research is too recent to allow evaluating the global effects, on fertility, longevity of animals for example. The decrease in CH_4 with high-concentrate diets is partially compensated for by an increase in other GHG due to higher upstream inputs, and one can wonder whether increasing concentrates in ruminant feeding is ethically sound. The use of lipids is a promising solution and does not present the same drawbacks. Most additives and biotechnologies tested for methane mitigation have not been proven to have a consistent and long-term effect for reducing CH_4 (essential oils, most plant extracts, vaccine against methanogens, direct-fed microbes); in some cases they are expensive (synthetic organic acids), or their use is banned or may be banned in many countries such as in EU (antibiotics, chloroform) (Doreau et al., 2011). Some compounds may be interesting in the future. Tannin extracts or tanning-rich plants may be efficient but do often decrease animal performances. Tea saponins have been shown to be efficient, but need more research. One promising additive, shown to be efficient in short- and long-term experiments, is nitrate (Van Zijderveld et al., 2012).

According to literature analysis, efficient and available techniques are thus lipids and nitrate. Several sources of lipids can be used. Unsaturated lipids, especially from linseeds, are recommendable as they modify microbial ecosystem resulting in an additional decrease in CH_4 production from carbohydrates. Lipids rich in medium-chain fatty acids such as coconut oil, palm kernel oil or palm oil derivatives have the same effect, but their high content in non-desirable saturated fatty acids may enrich milk or meat in these components, so that they are not considered. Concerning application of lipids, distribution as extruded seeds is a good solution, due to the significant amounts of lipids that can be easily included in the diet; on the contrary the incorporation of high amounts of oils in concentrates is limited by technological constraints. Moreover, a large-scale use is possible and lipids may be fed to most ruminants, provided they receive concentrates in their diet. However, CH_4 mitigation is partially compensated for by higher N_2O and CO_2 emissions linked to the production of oleaginous seeds compared to cereals, as shown by life cycle assessment method.

The use of nitrate in diet, although efficient as calcium nitrate, is controversial due to an effective risk of animal intoxication by nitrites in case of over-dosing, and of a potential rejection of this technique due to the negative image of nitrates. Nevertheless, this technique provides advantages as nitrates combined with hydrogen result in ammonia (NH_3) production in the rumen; it may contribute to spare other sources of ruminal NH_3, such as urea or a small part of oleaginous meals. The cost of the product is difficult to evaluate but may be reasonable, because of the present use of calcium nitrate as fertilizer.

Decreasing organic matter and nitrogen losses

Manure CH_4 production highly depends on manure storage conditions and application, but is proportional to undigested carbohydrates. When concentrate-rich diets are fed, undigested carbohydrates are lower than with forage-rich diets. When lipid supplements are fed, part of carbohydrates are replaced, leading to less undigested carbohydrates are present in faeces. Additives which may reduce CH_4 enteric production do not change or slightly modify carbohydrate digestibility. As a consequence, techniques which reduce enteric CH4 production either reduce or do not change the potential CH_4 production from manure.

Nitrogen losses result in various pollutions: N_2O as GHG, drainage of nitrates leading to eutrophication (Vertès et al., 2007) and NH_3 involved in acidification and human health, and responsible of unpleasant odours. Organic N is lost in faeces and urine. Most urinary N is as urea, which is rapidly transformed into NH_3 by faecal urease (Vaddella et al., 2010). Moreover, after redeposition NH_3 can also be transformed in nitrates and N_2O and it is generally assumed than 1% of the N-NH_3 is converted in N_2O. For this reason, one major objective is to reduce N losses, and especially urinary N. Indeed, mineral form of N (i.e. ammonia) result, in addition to NH_3 volatilisation, in higher N_2O emissions than organic forms (Eckard et al., 2010). However, it should be noted that this specific decrease in urine compared to urea is not taken into account by IPCC (2006) which considers urine and faeces as global manure.

Faecal N can be reduced when dietary N is highly digestible as for example protein from concentrates. The use of synthetic amino acids (AA) improves milk protein synthesis, and so, can reduce urinary N. In dairy cows, the use of the most limiting AA for milk production, methionine and lysine, increases the AA metabolic efficiency. This was known for high-N diets and has recently been demonstrated with low-N diets (Haque et al., 2012). This technique is now more expensive in ruminants than in monogastric animals, especially because of the need to protect AA against ruminal degradation, but could be considered in the future. Also the use of formaldehyde-treated meals (principally from soybean and rapeseed) can limit the excess of ruminal fermentable nitrogen, and thus limit urinary N excretion and thus ammonia emission (Van Duinkerken et al., 2005). Formaldehyde-treated meals are generally combined with urea in order to adjust dietary fermentable N supply. In spite of this, this technique is not frequent, and may be questioned in the future because they contain formaldehyde. The most promising technique is the reduction of protein content in diet, provided this does not reduce milk production. Accordingly, a replacement it has been suggested to replace grass-based systems by maize silage-based systems (Schils et al., 2013). However, this technique will put into practice a major change in production systems; moreover GHG emissions and nitrate leaching per ha are not reduced. An analysis of available data of N intake, excretion and secretion in milk using the whole-farm model MELODIE (Chardon et al., 2012) shows that diets with 14% protein do not limit milk production, on average. Hence, a reduction of dietary protein within a same production system can be seen as an available technique for limiting N losses of dairy systems.

The implementation of a reduction of dietary protein content is considered only for dairy systems. For beef systems, to date, our knowledge on existing practices using techniques such as improved dietary N efficiency is too limited to recommend an application. In addition, about 90% of total GHG emissions of beef systems are related to the cow-calf herd, of which the diet is generally low in protein content. In dairy systems, this technique is only considered for winter diets, as protein nutrition is not easy to monitor when cows are on pasture. This technique is rather easy to implement, because the measurement of milk urea is an excellent indicator of an excess of dietary N and is very well related to urinary N (Faverdin and Vérité, 1998). Moreover, contrary to many other mitigation techniques, the decrease in dietary N results in a spare of money for the farmer, especially by decreasing purchased concentrates. This is thus a win-win technique. Dissemination of this technique would need advertisement to assure farmers that a controlled limitation of dietary N does not compromise herd performances.

Optimizing grassland use

A part of GHG emissions from ruminants can be compensated for by a sequestration of carbon by grassland soil. This is an efficient way of GHG mitigation, known for a long time, but is barely taken into account. Recent studies show that soil C storage has been underestimated for methodological reasons such as neglecting storage in deep soil layers (Soussana et al., 2011). However, there is a large variability in C sequestration estimate, with wide inter-annual variations related to climatic conditions and agricultural practices (i.e. grazing, cut, sown grassland) (Soussana et al., 2007, Klumpp et al., 2011). The use of natural grasslands by livestock is not a mitigation technique *per se*, because it is "business as usual", but changes in grassland management may have considerable consequences: fertilization and animal stocking rate act on N_2O emission and nitrate leaching, draining wet soils reduce CH_4 emissions from grasslands. Given the a large diversity of grassland management among beef and dairy cattle systems, several ways of reduction of environmental impacts can be suggested.

One option is to increase grazing compared to production of conserved forage as hay or silage; these latter result in a more extensive exportation of biomass by cut, leading to *lower* C storage and *higher* GHG emissions (Soussana et al., 2007, Allard et al., 2007). Moreover, a prolongation of grazing period is possible if climatic conditions are favorable, and if soils are load-bearing and not too humid (Schils et al., 2013). For example, in plain areas of France, grazing period may be extended in many farms for at least 20 days, which may reduce emissions (NH_3, N_2O and CH_4) linked to barn (i.e. manure storage and spreading) and increase on-site C sequestration as more carbon is recycled at the paddock. A comparison of 9 European grassland sites confirmed that cutting *vs.* grazing was more beneficial for the net GHG balance (Soussana et al., 2007). In addition, faecal and urinary losses may produce less NH_3 on pasture than in building because they are excreted in separated places, with a slower conversion of urea to NH_3.
Also changes relative to temporary sown grasslands are promising, as an increase in lifetime (i.e. until 5 years) of temporary grassland will increase C storage due to less frequent ploughing. Moreover, a less frequent renewal of grasslands not only increases the net C sequestration but also reduces N_2O and NH_3 emissions and nitrate leaching, due to mineralization of N bound to soil organic matter. Other techniques such as composition of sown grasses (i.e. tannin rich grasses, sugar-rich grasses and legumes) may be used to reduce enteric CH_4. However to date there is no proven effect of nature of grasses on CH_4 emission: the interest of ryegrass rich in soluble carbohydrates is controversial, and a lower CH_4 emission with lucerne has been observed but remains to be confirmed (Doreau et al., 2011). Nevertheless, increasing the proportion of legumes in temporary sown grasslands contributes to the reduction of N_2O and NH_3 emissions, and of nitrate pollution related to lower use of mineral fertilizers (Rochette and Janzen, 2005).

Grassland management may be another mitigation option to decrease environmental impacts of livestock production systems. A reduction of N fertilization of permanent and temporary grasslands offers thereby the most promising techniques. In France, mineral N fertilization varies annually from zero unit per ha to more than 200 units per ha depending on regions and expected biomass, and a reduction of 10-20% may be considered at the highest application rates. Such a decrease, especially for high fertilized grasslands, does not impair animal performances when it contributes to avoid excess of dietary N. For example, Peyraud and Astigarraga (1998) showed that a strong decrease in grass N annual fertilization, which results in a decrease in grass N content and grass growth, may not change milk production of dairy cows using efficient N recycling, but drastically reduces urinary N; however milk production per ha is decreased. Sparing fertilizer while reducing environmental impacts is often a win-win technique. However, this option does not work for low-input, low-producing grasslands, where on the contrary, an increase in stocking rate may enhance C sequestration due to a stimulation of vegetation and a higher input of organic N supply.

Conclusions

Many techniques have been proposed for reducing environmental impacts by optimizing animal nutrition or management, in interaction with grassland use. A first step has been to select the most promising, or the more efficient techniques to be implemented from now on or in a near future. Additional work is needed to quantify the extent of mitigation and the cost of these techniques, which may be a key factor for their success of failure.

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3. Pig nutrition: impact on nitrogen, phosphorus, Cu and Zn in pig manure and on emissions of ammonia, greenhouse gas and odours

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Introduction

For a sustainable pork production, emission of pollutants from pig farms and use of non-renewable resources should be decreased as much as possible. Nitrogen and phosphorus from manure may be involved in eutrophication of freshwater or seawater. Besides, the world reserves of mineral phosphates are limited and should be preserved. In the same way, the accumulation of Cu and Zn in soils may impose a medium or long term toxicity risk on plants and micro-organisms. Ammonia emission from manure is involved in acidification and eutrophication, with recognized detrimental effects on soil status, forests and biodiversity. Pig production also contributes to the emission of greenhouse gas, especially CH_4 from enteric fermentation, and CH_4 and N_2O from manure.

Over the last decades, different ways to reduce the environmental impact pig production have been investigated. The nutritional approach has received great attention from researchers and legislative decision makers (Jongbloed et al., 1999b; Aarnink and Verstegen al. 2007). It relies on improvements in our knowledge of the physiology of pigs in order to achieve a better agreement between supply and requirement and improve nutrient availability in feedstuffs.

The aim of this paper is to give an overview of the nutritional possibilities to reduce N, P, Cu and Zn excretion by pigs, as well as emissions of ammonia and greenhouse gas, and to describe the means that could be or are already implemented in practice.

Reduction of N excretion in pig manure

The efficiency of protein utilisation by pigs depends on the dietary composition and the physiological status or the growth stage of the animals. In growing-finishing pigs fed a cereal-soybean meal diet, about 32% of N intake is retained (Dourmad et al., 1999b). Faecal N excretion which amounts to 17% of the intake corresponds to the undigested protein fraction and endogenous losses. Digested proteins are absorbed as amino acids which are used for protein synthesis. Obligatory losses of amino acids relate to protein metabolism (turnover) and renewal of skin and hair. The remaining amino acids, after protein deposition and obligatory losses, are catabolised and excreted mainly as urea. With conventional diets, this last fraction is often the most important. Average efficiency of N retention is lowest in sows (20-30%), intermediate in growing pigs (30-40%), and highest in weaners (45-55%) (Dourmad et al., 1999a).

Two complementary nutritional approaches can be used to improve the efficiency of N utilisation in pigs and, consequently, to reduce N excretion. The first approach is to ensure adequate protein/amino acid supply over time according to the growth potential of the animals or their physiological state. This requires a joint fitting of daily supply of energy and protein (amino acids), depending on genetic potential and stage of production, and on production objectives. In reproducing sows, N excretion was reduced by 20 to 25% when different diets are allocated for pregnancy and for lactation instead of a single diet for the whole period. Further improvements could be achieved with the use of multiphase feeding during pregnancy. Indeed, the protein requirement is much lower during the early pregnancy compared with later pregnancy (Dourmad et al., 2012). In fattening pigs, Latimier and Dourmad (1993) measured about 10% reduction in slurry N when different diets were applied during the growing and finishing periods, compared to feeding the same diet during both periods (Fig. 1).

The second approach is to improve the dietary amino acid balance and consequently reduce the required crude protein (CP) content of the diet. This can be obtained through a combination of different protein sources and/or the substitution of protein by inclusions of free amino acids. In fattening pigs, Dourmad et al. (1993) measured a 35% reduction of N excretion after improvements in the dietary amino acid profile) without affecting feed intake, average daily gain, feed efficiency and carcass composition.

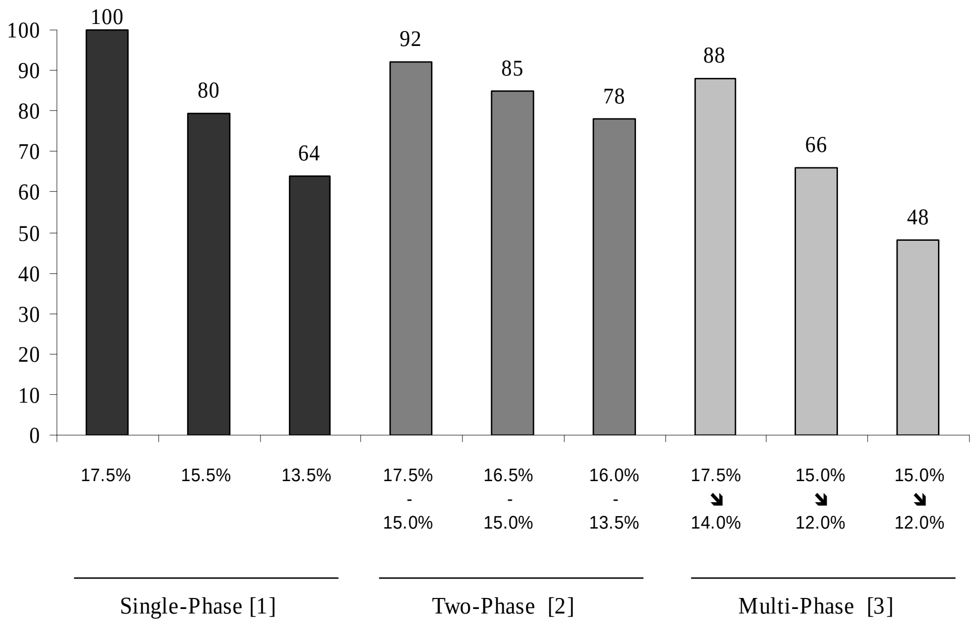

Figure 1. *Effect of dietary protein content and protein feeding strategy on N excretion (100 = excretion with one-phase feeding of a 17.5% CP diet). Adapted from [1] Dourmad et al. (1993), [2] Latimier et al. (1993) and [3] Bourdon et al. (1997).*

The ultimate reduction of N excretion can be reached when multiphase feeding is combined with a perfect balance between essential amino acids (close to the ideal protein concept), and with an optimisation of the supply of non-essential amino acids. Such a feeding strategy has been evaluated experimentally in fattening pigs by Bourdon et al. (1997). In that study, the use of a single diet (17.5% CP) over the whole growing-finishing period was compared to a “multiphase” strategy which consisted of the mixing of two diets (13.0 and 10.7% CP, re-equilibrated with free amino acids) in proportions that were optimised each week. Growth performance and carcass quality were similar, and N excretion was reduced by about 50% (1.83 vs. 3.56 kg N per pig) (Fig. 1). With this feeding strategy, N excretion represented only 50% of N intake. This can be considered to be close to the maximal attainable reduction in N excretion.

It must be pointed out that the development of such feeding techniques for reducing N excretion by pigs requires good knowledge of the amino acid availability in feedstuffs, and of the changes in amino acid requirements according to growing stage or physiological state. This is now within reach with the use of modelling techniques for predicting requirements (NRC, 2012; van Milgen et al, 2008; Dourmad et al., 2008) together with a better knowledge of variations in amino acid availability in feedstuffs (NRC, 2012; CVB, 2000; INRA-AFZ, 2004). Moreover, more numerous amino acids are now available for feed use (lysine, methionine, threonine, tryptophane and valine) which allows a further reduction in dietary protein content. This can also be achieved in practice by using computerized blend feeding systems which allow adapting the diet composition on a daily or weekly basis (Feddes et al., 2000; Pomar et al., 2007).

The reduction in dietary protein content results in a lower proportion of N excreted in urine relative to faeces, which might affect the utilisation of manure N after field application (Sørensen and

Fernandez, 2003). In a study of Portejoie et al. (2003) the ratio ammoniacal N:total N in fresh manure decreased from 0.79 with the 20% CP diet to 0.63 with the 12% CP diet. However, in the studies of Gerdemann et al. (1998) and Sørensen and Fernandez (2003) the plant availability of slurry N was not clearly affected by the dietary protein content.

Feeding strategies with reduced protein content are already implemented in practice in many countries. Different strategies are compared in table 1. The first two-strategies correspond to the hypothesis used for the official calculation of N excretion in France (Corpen, 2003). Compared to the one-phase feeding strategy, used as reference, the two-phase feeding strategy with limited CP contents, reduces N intake and N excretion by 10 and 15% respectively. A further reduction in dietary CP and consequently N excretion could be achieved at rather short term by incorporation of more amino-acids in free form and by using multiphase feeding for fattening pigs (Garcia-Launay, 2013, Table 1).

Table 1. *Protein feeding strategy and N excretion (Corpen, 2003; Garcia-Launay et al., 2013)*

	Corpen, 2003		**Perspectives**	
	Standard	**Two-phase**	**Two-phase**	**Multiphase**
Crude protein, g/kg				
Gestation	170	140	120	120
Lactation	170	165	155	155
Pre-starter	210	200	180	180
Starter	190	180	160	160
Grower	175	165	150	150
Finisher	175	150	130	110
Average	177	158	140	131
N per slaughter pig (0-115 kg)				
Intake	9.10	8.16	7.23	6.78
Retention	2.89	2.89	2.89	2.89
Excretion	6.06	5.13	4.22	3.78
% of standard	100	85	70	63

Table 2. *Effect of protein feeding of fattening pigs on slurry characteristics and ammonia volatilisation (Portejoie et al., 2004).*

	Dietary crude protein content		
	20%	**16%**	**12%**
Slurry composition			
Amount (kg pig^{-1} d^{-1})	5.7	5.1	3.6
DM (%)	4.4	4.6	5.9
Total N (g N/kg)	5.48	4.30	3.05
Total ammoniacal N (g N/kg)	4.32	3.13	1.92
pH	8.92	8.61	7.57
N balance (g pig^{-1} d^{-1})			
Retention	23.2	23.5	21.9
Excretion	40.7	27.6	15.0
Ammonia volatilisation	17.4	13.8	6.4
Available to plants	23.3	13.8	8.6

Reduction of ammonia emissions

By changing feeding practices, it is possible to influence urea concentration in the urine and the pH of slurry, which will affect ammonia release (Van de Peet-Schwering et al., 1999). When pigs are fed low CP diets, urinary urea concentration and pH decrease (Canh et al, 1998; Portejoie et al, 2004). When water is available ad libitum, feeding low CP diets also results in lower urine production due to decreased water consumption (Pfeiffer et al, 1995; Portejoie et al., 2004). The changes in slurry characteristics result in lower ammonia losses during housing, storage and following application of slurry (Canh et al., 1998; Hayes et al., 2004; Portejoie et al., 2004; Jarret et al., 2011). For instance, in the study of Portejoie et al. (2004) ammonia emissions over the whole period from excretion to field application, was decreased by 63% when dietary CP was decreased from 20 to 12% in finishing pigs (Table 2). However ammonia emission was rather similar when expressed as a % of N excreted.

The electrolytic balance (EB), calculated as ($Na^+ + K^+ - Cl^-$), is often used by nutritionists to evaluate the acidogenicity of the diet, a decrease in the EB resulting in a decrease in urinary pH. When dietary CP content is reduced, EB also decreases because of the high K content of most protein sources. This partly explains the effect of CP on urinary pH. However, as shown by Canh et al. (1998), more drastic changes in urinary pH and ammonia volatilisation can be obtained by inclusion of the Ca salts $CaSO_4$ or $CaCl_2$ instead of $CaCO_3$. The addition of Ca-benzoate (Canh et al., 1998) or benzoic acid (Guingand et al., 2005; Guiziou et al., 2006) was also effective in reducing slurry pH and ammonia volatilisation (by 25 to 40%), because these products are metabolized into hippuric acid which is rapidly excreted in urine. A similar effect (25% reduction in ammonia emission) was observed with adipic acid (van Kempen, 2001) which is partially excreted in urine.

Urea N excretion can also be reduced by including fibrous feedstuffs in the diet. With more fermentable non-starch polysaccharides (NSP) in the diet, some of the N excretion is shifted from urine to bacterial protein in faeces (Canh et al., 1998; Kreuzer et al., 1998, Sørensen and Fernandez, 2003; Jarret et al., 2011, 2012), while total N excretion is not affected. Moreover, slurry pH is decreased with the use of fermentable NSP due to volatile fatty acid (VFA) formation in the hindgut of the pig and in the slurry (table 1). Canh et al. (1998) measured a linear relationship between NSP intake and slurry pH or ammonia volatilisation; for each 100 g increase in NSP intake, the slurry pH decreased by 0.12 units and the ammonia emission from slurry decreased by 5.4%. This is consistent with the recent results obtained by Jarret et al. (2012) who compared two diets differing in their fibre content (table 3)

Table 3. *Effect of fibre content in fattening pigs diet on composition of excreta, N balance and ammonia emission (Jarret et al., 2012).*

	Control	**High-fiber**	
Crude Fiber, g/kg	29.4	49.0	
N balance, g/d			
Intake	5.9	55.5	
Excretion	28.7	30.3	
% in faeces	26.3	40.0	***
pH urine	8.28	7.15	***
pH faeces	8.39	8.11	***
VFA in faeces, mg/L	62.6	260.0	***
Ammonia emission (%)	17.9	12.4	***

The utilisation of manure N after field application may also be affected by the level of NSP in the diet, because a greater proportion of N is excreted in faeces in more complex organic forms. Availability of slurry N was reduced after the inclusion of dietary fibre with low fermentability (Sørensen and Fernandez, 2003), whereas it was not affected when the dietary content of fermentable structural carbohydrates increased (Gerdemann et al., 1998; Sørensen and Fernandez, 2003), although in all cases the proportion of N excreted in urine decreased. Combined with the proportion of urinary N, the fibre content of faeces gives a good prediction of the plant short term availability of slurry N (Sørensen and Fernandez, 2003).

Effect of feeding on direct emissions of greenhouse gas

Pig nutrition may affect both emissions of N_2O and CH_4. According to IPCC (2006) emissions of N_2O are calculated from N excretion and specific emission factors that depends on manure management. This means that according to this procedure of calculation, N_2O emission will be proportional to N excretion, and all strategies that will reduce N excretion will also affect direct N_2O emissions, in the same proportion. However it should be confirmed by experimental results since, to our knowledge, this has not yet been evaluated in the literature.

CH_4 has mainly two origins in pig production: enteric fermentations and fermentations from collected and stored manure. Enteric fermentations vary according to the physiological status of the animal and the amount of digested fibre ingested (*DigFib*). DigFib is the difference between digested organic matter and digested protein, fat, starch and sugar, as calculated in INRA-AFZ tables (2004). The loss of energy as methane *$E(CH_4)$* can be obtained by multiplying *DigFib* by 670 or 1340 J/g for growing pigs and sows, respectively (Noblet *et al.*, 2004). Methane production (*CH_4 Enteric*, kg) can then be calculated from *$E(CH_4)$*, considering methane calorific value equal to 56.65 MJ/kg (IPCC, 2006). This is illustrated in table 4 from the results of Jarret et al. (2012) who compared two diets with different fibre contents.

According to IPCC(2006) Tier 2 methodology CH_4 emission from stored manure can be calculated as : *CH_4 Manure (kg) = VS* x *B_0* x *FCM*, with *VS* = volatile solids in excreta, roughly considered as amount of organic matter excreted (kg), *B_0* = maximum methane producing capacity (m^3/kg organic matter) and *MCF* = a methane conversion factor for the management system considered, expressed as a percentage of maximum potential. Volatile solids excreted depend on the digestibility of feed organic matter and is mainly affected by dietary fibre content. Volatile solid can be calculated from OM digestibility values in feed tables (INRA-AFZ, 2004). This is illustrated in table 4 from the results obtained by Jarret et al. (2012) who compared a conventional and a high fibre diet. Volatile solid excreted per pig per day was significantly increased in the high fibre diet (by 64%) whereas B_0 of excreta did not differ between treatments. This resulted in a 76% higher CH_4 emission per pig during a simulated storage of 100 d, for the high fibre diet. In the same way, when comparing diets with different types of high fibre feed ingredients (rapeseed meal, sugar beet pulp and DDGS), Jarret et al. (2011) observed only limited differences in B_0 values, but a significant increase of excreted VS, resulting in a much higher potential of CH_4 emission per pig for the high fibre diets.

Table 4. *Effect of fibre content in fattening pigs diet on volatile solid of excreta (VS), composition of excreta, N balance and ammonia emission (Jarret et al., 2012).*

	Control	**High-fibre**	
Crude Fibre, g/kg	29.4	49.0	
Digestible “fibre”, g/kg feed	74.8	110	***
Enteric CH_4, L/pig/d	3.1	4.6	***
VS, g DM/pig/d	192	315	***
B_0, L CH_4 / kg OM	377	376	
CH_4 production, L/pig/d			
storage simulation (100 days, 30°C)	55	97	***
MCF, %	71%	77%	*

Composition of the diet also affects the dynamic of methane emission. Although B_0 values of excreta from pigs fed a high protein diet (471 L CH_4/kg OM) tended to be higher than from a low protein diet (449 L CH_4/kg OM) the emission during storage was accelerated for the low protein diet, in relation with a lower pH and a lower ammonia concentration (Jarret et al., 2011). In the same way, methane emission started faster from effluent from pigs fed a high fibre diet which had also lower pH and lower ammonia concentration. These results indicate that MCF values are affected by duration of storage and depend on the type of diets. For instance in Jarret et al. (2011) for 50 days of storage in mesophilic conditions MCF varied from 2% for the high protein diet to 54% for the high fibre diet (from 18% to 75% after 100 days of storage) the value for the low protein diet being intermediate.

Effect of feeding on odours

Odours are mainly associated with volatile compounds that pigs excrete with manure, or which are released during manure storage (de Lange et al., 1999). These volatile compounds are generated by the microbial conversion of feed in the large intestine of pigs or in manure pits. Based on a literature review, Le et al. (2005) suggested that CP and fermentable carbohydrate (FC) would play a major role in the production of odour nuisance from pig production.

Few studies have evaluated the direct effect of diet manipulation on odour production, mainly because it is difficult to assess odours objectively. As mentioned previously, protein nutrition affects ammonia production, but the ammonia production is not well correlated with odour strength (Le, 2006). Using olfactometry, Hayes et al. (2004) showed a significant reduction in both ammonia and odour emissions when CP content was reduced, but this was not observed in all studies. Hobbs et al. (1996) reported that the concentration of nine out of ten odorous compounds in the air was significantly reduced when low CP diets were fed to the pigs. Le (2006) also found a reduction by 80% in the odour emission, as determined by olfactometry, when dietary CP was reduced from 18 to 12%. Moreover, the results from the same author suggested an interaction between effects of CP and FC on odour production suggesting that odour production depends also on the balance between dietary CP and FC. The manipulation of gut fermentation could also be a way to alter the production of odorous compounds such as skatole (de Lange et al., 1999). Using a different methodology for assessing "pleasantness", "irritation" and "intensity" scores of odours, Moeser et al. (2003) were able to significantly discriminate between diets differing in composition. The diets that yielded manure with the worst odour were high in sulphur (rich in garlic or feather meal), whereas a purified diet mainly based on starch and casein presented the lowest score (most pleasant). This is in agreement with the >700% increase in odour emission measured by Le (2006) with diets supplemented with a sulphur-containing amino acid (methionine) at high levels.

Reduction of P in pig manure

In growing-finishing pigs fed a cereal-soybean meal diet, about 45% of P intake is absorbed, about 30% is retained, and the remaining 15% is excreted via urine (Poulsen et al., 1999). Totally, with such diets, 70% of P ingested is excreted either via the faeces or via urine. In order to reduce P losses, P supplied to pigs should be adjusted to their requirement, and strategies to improve P availability should be implemented (Poulsen, 2000; Knowlton et al., 2004). This approach relies on an accurate knowledge about feed P availability and P requirement according to the physiological status of pigs.

A first approach to improve P uptake efficiency is to use highly digestible mineral P supplements. For example, monocalcium rather than dicalcium phosphate should be used because of its much higher digestibility (INRA-AFZ, 2004). However, most strategies implemented to reduce P excretion by pigs refer to improvements in phytic P utilisation (Jongbloed et al., 1992b).

In many countries, microbial phytase is currently introduced in diets for pigs because of its well-documented positive effect on P digestibility. Total P supply may be decreased, resulting in a 40 to

50% reduction of P excretion (Jongbloed and Lenis, 1992a; Latimier et al., 1994, Table 3). However, the response of digestible P to graded levels of microbial phytase is curvilinear, and the maximum P digestibility never exceeds 60-70%, even at high levels of phytase supplementation. Based on literature reviews, equivalency equations of digestible P for microbial phytase were established (Kornegay, 2001; Johansen and Poulsen, 2003) and can be used for diet formulation.

In the same way as for protein and amino acid supply, the second approach to reduce P excretion is to ensure adequate supplies over time according to the growth potential of the animals or their physiological status. This requires a precise evaluation of pigs' P requirements, as well as P availability in feed ingredients. In practice, this can already be achieved by the use of a feeding system relying on, e.g., P apparent digestibility (CVB, 2000; INRA-AFZ, 2004) and the factorial determination of P requirements (NRC 2012, Jongbloed et al., 1999a; Jondreville and Dourmad, 2005). Finally, this allows the reduction of safety margins when formulating pig diets, resulting in a decrease in P excretion.

Feeding strategies with reduced phosphorus content are already implemented in practice in many countries. Different strategies are compared in table 5. The first two-strategies correspond to the hypothesis used for the official calculation of P excretion in France (Corpen, 2003). Compared to the one-phase feeding strategy, used as reference, the two-phase feeding strategy with limited P content reduces P intake and P excretion by 13 and 19%, respectively. A further reduction in dietary P and consequently P excretion could be achieved at rather short term by using higher level of phytase and by using multiphase feeding for fattening pigs (table 5).

Table 5. *Phosphorus feeding strategy and P excretion*

	Corpen, 2003		**Perspectives**
	Standard	**Two-phase**	
P, g/kg			
Gestation	6.5	5.0	4.5
Lactation	6.5	6.0	6.0
Pre-starter	7.5	6.8	6.0
Starter	6.5	5.8	5.0
Grower	5.8	4.8	4.2
Finisher	5.8	4.4	3.8
Average	6.0	4.9	4.3
P per slaughter pig (115 kg)			
Intake	1.91	1.54	1.35
Retention	0.60	0.60	0.60
Excretion	1.31	0.94	0.76
% of standard	100	72	58

Effect of nutrition on Cu and Zn in pig manure

Cu and Zn are involved in many metabolic functions, and their provision in sufficient amount in pig feeding is indispensable to ensure good performance and animal health (Revy et al., 2003, Jondreville et al., 2002). However, because they are used as growth promoters at pharmacological levels, or because large safety margins are applied, Cu and Zn are often oversupplied in pig diets. Consequently, these elements are highly concentrated in pig manure and accumulate in soil, where they may impose a medium or long-term toxicity risk to plants and micro-organisms (Jondreville et al., 2003). Moreover, when a treatment is applied to the slurry, Cu and Zn will follow the solid fraction where their concentration often exceeds the maximal values allowed for the utilisation of these products as organic fertilisers. The only way to decrease the concentration of trace element in manure is to restrict their incorporation in the diet.

The incorporation of 150 to 250 ppm Cu in pig diets has been employed for a long time because of its growth promoting effect (Braude, 1980). This practice is currently authorized in EU allowing diets containing a maximum of 170 ppm Cu for pigs up to 12 weeks. After 12 weeks of age, the use of Cu as a growth factor is no more allowed within EU, and the maximal level of incorporation is 25 ppm. Compared to the former allowed inclusion (175 ppm up to 16 weeks of age and 100 ppm thereafter (*former*, Table 6), this results in a drastic reduction of Cu in manure by almost 60% (*actual*, Table 6). Nevertheless, the practical supply remains higher than the usually published requirements (less than 10 ppm), and average retention efficiency is still less than 1%.

Supplementing weaned piglets diets with 1500 to 3000 ppm Zn as ZnO has also been reported to stimulate their growth (Poulsen, 1995). In fact, in 2003 the maximal allowed Zn incorporation in pig diets was reduced to 150 ppm, compared to 250 ppm before (EC, 1334/2003). These levels are much closer to the published requirement, which varies between 100 and 50 ppm depending on growing stage and authors (Revy et al., 2005). However in some EU countries supplementation with 2500 ppm Zn is still allowed as medication, resulting in an increased excretion.

As for P, the main way to reduce Cu and Zn in pig manure is to adjust the supplies to the requirement, and to improve the availability to the pigs. Zinc requirement of weaned piglets was recently evaluated to be about 90 mg/kg diet (Revy et al., 2005) which is consistent with the former recommendations and below the usual level in practice. When microbial phytase is incorporated in the diet, the Zn supply may be reduced because of increased availability. In weaned piglets, incorporation of 500 phytase units/kg diet was evaluated to be equivalent to the supply of 30 ppm of Zn as Zn sulphate (Jondreville et al., 2005).

Table 6. *Estimates of Zn and Cu balance[1] according to different scenarios of supply in pig feeding. Former EU regulation, actual EU regulation and perspectives.*

	Cu			Zn			
	Former	**Actual**	**Persp.**	**Former**	**Actual**	**"Actual"[3]**	**Persp.**
Concentration (ppm)							
Prestarter	175	170	10	250	150	2500	70
starter 2	175	170	10	250	150	150	50
fattening pigs	120	25	10	250	150	150	30
sows	100	25	10	250	150	150	70
Balance (0-110 kg BW)							
intake (g/pig)	40.4	13.0	3.1	78.3	47.0	63.4	12.2
excreted (g/pig)	40.3	12.9	3.0	75.8	44.5	61.0	9.7
Slurry (mg/kg DM)	1060	348	80	1995	1171	1604	255
Delay, years	50	167	1040	99	175	125	1160

[1] calculated according to Jondreville et al. (2003), expressed per slaughter pig, including intake and excretion by sows.
[2] delay to reach 50 mg Cu or 150 mg Zn/kg soil DM
[3] in case of use of 2500 ppm of zing in pre-starter diet as allowed in some EU countries

With the present EU regulation, Cu and Zn contents in manure DM (about 350 and 1250 mg/kg DM, respectively) are below the maximal concentration allowed in sewage sludge in France (1000 and 3000 mg/kg DM, respectively), but they exceed the concentration allowed for organic fertilizers (300 and 600 mg/kg DM, respectively). Assuming that 170 kg N/ha are spread each year it will take 160-170 years for the soil to reach 50 mg Cu or 150 mg Zn /kg soil DM (table 6). This is much longer than with the previous regulation (50 to 100 years).

But although the situation has been drastically improved by these new regulations, Cu and Zn inputs to soil with a manure application rate of 170 kg N/ha still exceed the export by crops. In the future, further reductions in Cu and Zn excretion should be possible (*Perspective*, table 6), resulting in a better agreement between spreading and export by plants. However, this will require a better understanding of the factors that affect Cu and Zn availability and a more precise evaluation of the requirements.

Conclusions

Improving the efficiency of nutrient utilisation by livestock is an efficient way to reduce the excretion in slurry. In a whole-farm perspective this is an efficient way to reduce the import of nutrients, especially N, P and trace elements, from outside the farm. Moreover, gaseous emissions from livestock housing and during storage and spreading of manure are also affected whenever livestock nutrition is changed, due to changes in chemical composition of the effluents.

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4. IMPEL Projects 2009-2012

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About IMPEL

The European Union Network for the Implementation and Enforcement of Environmental Law (IMPEL) is an international non-profit association of the environmental authorities of the EU Member States, acceding and candidate countries of the European Union and EEA countries. The association is registered in Belgium and its legal seat is in Bruxelles, Belgium.

IMPEL was set up in 1992 as an informal Network of European regulators and authorities concerned with the implementation and enforcement of environmental law. The Network's objective is to create the necessary impetus in the European Community to make progress on ensuring a more effective application of environmental legislation. The core of the IMPEL activities concerns awareness raising, capacity building and exchange of information and experiences on implementation, enforcement and international enforcement collaboration as well as promoting and supporting the practicability and enforceability of European environmental legislation.

The expertise and experience of the participants within IMPEL make the network uniquely qualified to work on both technical and regulatory aspects of EU environmental legislation.

Information on the IMPEL Network is also available through its websites at:
http://europa.eu.int/comm/environment/impel
www.impeltfs.eu

IMPEL has the following Clusters: *Improving Implementation of EU Environmental Law* (Permitting, Inspection Enforcement and Smarter Regulation) and Cluster *Transfrontier Shipment of Waste.*

COMPARISON PROGRAMME ON PERMITTING AND INSPECTION OF IPPC PIG FARMING INSTALLATIONS IN IMPEL MEMBER COUNTRIES 2009

General information about the project

The aim of the project was for IMPEL members to learn from each other, to exchange experiences and know-how and identify good and where possible best practices in the regulation of pig farms. The project would also develop recommendations to assist regulators in improving the environmental performance of pig farms.

This report describes how the project was undertaken and sets out the key issues and conclusions relating to a number of environmental issues relating to pig farming identified as important by IMPEL members. It also contains a range of recommendations to improve the regulation of pig farms and considers how further collaboration by IMPEL members on this issue can proceed.

Participant countries were: Netherlands, Latvia, Germany, France, Italy, Portugal, Sweden, Cyprus, Estonia, Republic of Ireland, United Kingdom (England and Wales, Scotland, Northern Ireland, Poland, Hungary, Romania, Slovakia, Slovenia, Czech Republic, Denmark.

In order to investigate these issues in more detail, a questionnaire was developed by the core team which sought information from IMPEL members on how each of the key (housing system, abatement techniques, manure storage, manure spreading, odour) environmental issues was addressed during the regulatory process for implementing IPPC– applying for a permit, determining permit conditions, monitoring and inspection. The questionnaire was circulated to IMPEL coordinators for distribution to relevant authorities. Questionnaire generated 26 responses, with input from 26 authorities across 17 Member States.
In order to understand the regulatory and environmental issues in the Member States, three visits were made to Member States. In each case joint inspections were carried out at IPPC pig farms to provide practical experience of the variety of farms in the EU and to discuss issues with the operator. Meetings were held to discuss the regulatory background in the Member State/region and to discuss the site permit in detail. The visits included participants from a number of Member States in order to provide different perspectives:

- Modena, Italy, 1-2 April 2009.
- Latvia, 23-24 April 2009.
- Schwerin, Germany, 7-8 May 2009.

The project concluded with a workshop in Utrecht, the Netherlands, on 10-12 June 2009 for 31 participants from 20 Member States. The workshop began with a visit to PTC Barneveld in the Netherlands to view some aspects of Dutch intensive pig farming in practice and methods to reduce environmental impacts.

Concerns raised by permitting and inspecting authorities

Housing systems

- It is difficult for permitting authorities to determine what is BAT **(SLO, FR, UK, EE).**
- Access to, and understanding of information, is a problem **(DK).**
- Potential changes (e.g. cost) required to meet BAT and the associated timescales can be a problem **(UK, Northern Ireland).**
- Many farms have a range of housing systems on their farm. Many use straw-based solid floor systems - the acceptability of which is not covered in detail in the BREF **(UK, England and Wales).**
- The standard system is for deep slurry storage under slats. Operators argue that alternatives given in the BREF are expensive, not workable and would be difficult to establish as the building supply industry is not set up to use these **(UK, Scotland).**
- The flushing channel system is not considered to be BAT for new build systems. However, when changes take place on a farm it is not clear if the old flushing channel system still BAT or are the changes so big that it has to be considered as a new system and is not BAT **(NL)**

Abatement techniques

- The most common reason for the lack of air pollution abatement technology is the cost to the operators **(DK, IE)**
- The BREF provides little information on this issue and attempts to model specific emissions for sensitive receptors have proved to be very difficult, thus creating problems in defining what controls are needed **(UK England and Wales)**
- Difficulties to provide accurate estimations of emissions from different types of housing **(FR)**
- Application of BREFs is difficult **(HU).**

Manure storage and spreading manure

- The links between animal farming, agronomy and environment, especially for water quality (phosphorus and nitrogen). For example, there is no reliable control method which would guarantee the right balance of fertilization **(FR)**
- Difficulty to coordinate the application of some provisions, whose effects are opposite, such as provisions regarding manure treatment (which needs much energy) and measures to limit energy consumption **(FR)**
- Availability of land for spreading slurry- Difficulty of providing adequate demonstration that slurry is being applied to land in accordance with crop nutrient requirements, in particular phosphorus; insufficient land available **(UK Northern Ireland, RO, DE, PT)**
- Making an accurate assessment of leaching potential in a specific area and an estimation of the effect of measures can be difficult **(DK)**

Other environmental issues identified by member states

- Odour- due to the close proximity of the pig farms to residential areas and dense concentration of large pig farms within some areas **(CY, HU, UK Northern Ireland)**
- High concentrations of salts in the slurry causing problems in the use of slurry as fertiliser or for irrigation **(CY)**
- Eutrophication- how to deal with critical loads and how to evaluate the biotopes correctly with respect to their sensitivity to nitrogen and phosphorus **(DE, DK)**
- Ammonia emissions- Potential for damage to designated habitats – ammonia monitoring being carried out around some pig farms and local habitats. Application of ammonia abatement technology - cost prohibitive **(UK Northern Ireland and Scotland)**
- Difficulties to evaluate which is the most important: reduction of the amount of emitted ammonia gas or pig welfare considerations. I.e. the use of litter (straw) in pig housing systems is considered to be a good choice concerning pig welfare but the emission of ammonia gas is high compared to other housing systems **(DK)**
- Insufficient knowledge on impacts and transfer of veterinary medicines, detergents, disinfectants, etc**. (DE)**

Conclusions

This project has addressed a range of regulatory issues relating to intensive pig farms. However, project participants have agreed that it is only the start of a process of improving understanding of the issues and improving regulation by IMPEL members. It was agreed, therefore, that activities should continue after the formal completion of the project itself.

In particular, project participants noted that the Technical Working Group for revision of the intensive farming BREF could benefit from the conclusions and detailed information arising from the project and follow-up activities, both directly and to guide further investigation by the TWG. This report makes specific recommendations for the TWG, but it is also clear that IMPEL members have further information from which the work of the TWG could benefit and that there are questions or issues that the TWG should examine in more detail than has been possible in this project

The participants concluded that the information exchange forum established for the project should be maintained for further exchange by Member State authorities. The types of information that could be shared include:

- Examples of permits issued in each Member State.
- Development of a standard list of permit requirements.
- Examples of guidance issued by the Member States to operators.
- Assessment methods for different environmental problems.
- Practice on taking into account Programmes of Measures under the Water Framework Directive.

IMPROVING PERMITTING AND INSPECTION OF IPPC PIG FARMING INSTALLATIONS BY DEVELOPING PRACTICAL GUIDANCE 2011-2012

General information about the project

The guidance book is the result of the collaboration of the countries represented in the IMPEL project "Improving permitting and inspection of IPPC pig farming installations". The aim of the project is to develop practical tools for IPPC pig farm inspectors.

The structure of the book is based on activities on a pig farm. This fits the daily practice on a pig farm and a regular inspection on a pig farm.

The guidance book is the result of the collaboration of the countries represented in the IMPEL project "Improving permitting and inspection of IPPC pig farming installations". The project team initiated the book by writing the different chapters and paragraphs in draft. Subsequently, a final workshop was organized
Participant countries were: Netherlands, Latvia, Lithuania, France, Italy, Portugal, Cyprus, Estonia, Republic of Ireland, United Kingdom, Poland, Romania, Slovenia, Czech Republic, Spain, Sweden.

Participants filled in a questionnaire in order to collect in depth information on problems or challanges related to IPPC pig farming, to provide inventory of good examples of permitting and inspection tools that already has been developed, to make an inventory of need for common guidance that should be developed
One sites visit was carried out in Lisbon, Portugal and two workshops were held Utrecht, The Netherlands.
An interim report was issued in November 2011 and in February 2013 the final report was issued.

Relation with other European Directives

It is usually not possible to consider the IED Directive in isolation. This is for the following reasons:

- The IED Directive applies to pig farms above a specified capacity. However, some Member States also apply the same or similar approaches to pig farms below this capacity.
- Some aspects of pig farming, particularly, manure spreading, may be difficult to include within IED regulation and are addressed under other regulatory regimes.

For farms it is not always easy to define what is part of the installation and what not. The housing system for pigs forms the major part of a pig farm installation. Outside the housing, manure storage, installations for manure treatment and storage for instance feed or fertilizer are in most cases also part of the installation. The fields where the manure from the pigs is spread are usually not considered as part of the installation. Despite this, the BREF intensive rearing of poultry and pigs includes some techniques that are not always applied on installations covered by the Directive, like landspreading techniques. The reason for considering landspreading in the BREF is to prevent the benefits of a measure applied by a farmer to reduce emissions in the beginning of a chain being cancelled out by later applying poor landspreading management or techniques at the end of the chain.

Relation to Habitat Directive

In some European regions with a large concentration of intensive animal husbandry the emissions of ammonia (NH_3) to the atmosphere create severe risk to not realize the targets mentioned in the Habitats Directive (HD). Purpose of the HD is to protect certain with extinction endangered species and habitats, to protect biodiversity and tot conserve a valuable area of nature in Europe.
In the southern and eastern parts of the Netherlands the concentration of ammonia en nitrogen oxides (NOx) is a serious problem to fulfill these purposes. The Habitats Directive is in the Netherlands translated in national legislation. In the concerning parts of the Netherlands this legislation is elaborated in provincial and regional rules. These rules require large reduction of ammonia emissions and result in very strict nature permits for intensive animal farming. Frequently larger reduction of ammonia emissions is required than could be asked on base of the IED. Mostly end of pipe solutions, like air-scrubbers, are used to reduce the emissions. In the concerning regions a lot of effort on supervision and enforcement is invested to secure that these ammonia removing techniques operate well.

Relation to Water Directive and Nitrates Directive

The BREF document indicates that the main environmental impacts related with nitrogen and phosphorus emissions to surface water and groundwater result from farming activities.

Waste water emissions can contaminate soils and clean waters such as surface waters, rain waters or ground waters. The contamination may be biological but also physical (solids in suspension), chemical with special attention to some heavy metal that can occur from the pig farming activity such as Copper and nutrients as Phosphorous and Nitrogen.

When spreading takes place in a vulnerable zone, application must comply with the Nitrates Directive action programme

Results of questionnaire

The questionnaires concluded that there is need for more guidance like:

- How to work with the BREF?
- Inspection guidance in case of complaints
- How to do an odour management assessment?
- How to do a fly management assessment?
- Assessment of BAT for housing
- Inspection instruction specific for pig sector

Problems that came up are:

- The determination of what is BAT due to many different building types/designs and slurry systems
- As there is no ELV settle in BAT, it is difficult to establish quantitative targets and performance indicators.
- Difficult to validate/confirm the actual numbers of pigs on farms due to the differing stages of production; different pig weight ranges, etc
- Behaviour of pig farmers, most of them are independent, not educated.
- Sector economical situation

Inspection guidance book for intensive piggeries

- Pigs in housing
- Manure storage (slurry)
- Manure spreading on own land
- Storage of waste
- Feed storage
- Transportation
- On-farm manure treatment
- Waste water treatment
- Storage of carcases
- Feed mixing
- Storage of liquid manure fraction
- Storage of solid manure
- Storage of dangerous substances (Diesel, Fertilizer)
- Inspection preparation
  - Which information should be collected?
  - What should be clear?
- On site inspection: Checklists for the major activities and general tips
- After inspection

Every chapter from guidance mentioned above has the following sections:

- Environmental importance
- Relation to IED/ BREF
- Execution
- Main questions for inspection

Conclusions

Guidance book is written for inspectors that are responsible for the inspection of IPPC pig farms. The guidance is intended for all inspectors in the European Union and is produced with great care, with attention to details, taking into account the different legislations of the European countries. The content of this guidance book is therefore not a complete overview of legislation on a pig farm, but is intended as a helpful tool to understand the regulation on an European level and in the context of the daily practice on a farm.

References

http://impel.eu/projects/ippc-pig-farming/

Best Available Techniques (BAT) reference documents; Bref IRPP 2003

Best Available Techniques (BAT) reference documents; Bref Draft 1, 2011

Inspection guidance book for intensive piggeries**-** *A practical book with guidance on activities on a pig farm* (IMPEL 2013)

5. The impact of livestock on the environment and technical solutions available in Germany

Ewald Grimm

KTBL

Review on the impact of livestock on the environment (air, water, soil)? Which pollutants are of particular concern and why?

In Germany, environmental impacts caused by aerial emission from livestock installations (especially animal houses and manure storage) are of particular concern in society and politics.
With regard to the environmental impact, the emissions of odour, ammonia, greenhouse gases (methane and nitrous oxide), and increasingly particulates/bioaerosols have the greatest importance. For the approval and (if required) the monitoring of facilities on individual farms, however, greenhouse gases do not play any role because currently no emission and immission limits exist.

Table 17. Overview of sources, causes, and potential effects of emissions from farm animal housing facilities

Kind of emission	Source	Cause	Potential effect
Odour	animal houses and yards, storage facilities for solid and liquid manure as well as feed-stuff (especially silage)	microbial degradation of organic substance (e.g. faeces, urine, and feedstuff), natural odour	offensive odour
Ammonia	animal houses and yards, storage facilities for solid and liquid manure	microbial degradation of urea and uric acid in the excrement	damage to sensitive plants at high ammonia concentration, eutrophication and acidification of ecosystems due to nitrogen deposition, formation of secondary particles (fine dust).
Dust (particles, bioaerosols)	animal houses, feed management	animal activity, litter, conveying, grinding, mixing, and dispensing of feedstuff	health hazards due to diseases of the respiratory tract and allergies
Methane	ruminants, animal houses and yards, storage facilities for solid and liquid manure	feed fermentation in the rumen, anaerobic microbial degradation of solid and liquid manure	emission of climatically relevant gases contributing to the global greenhouse effect
Dinitrogen monoxide	animal houses and yards, storage facilities for solid and liquid manure	nitrification and denitrification processes in solid and liquid manure	

*(**source**: Guideline VDI 3894/1 “Emissions and immissions from animal husbandry - Housing systems and emissions - Pigs, cattle, poultry, horses“ 2011-09)*

Odour emission may cause annoyances in the vicinity of livestock installations. In order to protect residents against significant odour annoyances, minimum distance regulations for the assessment of odour and the spatial separation of farms and dwellings or residential areas have been established by the Association of German Engineers (VDI; Guideline VDI 3894/2 “Emissions from and impacts of livestock operations - Method to determine separation distances – Odour”, 2012-11). Odour assessment is also based on the so-called “Odour Immission Regulation“ (Geruchs-immissionsrichtlinie – GIRL; http://www.lanuv.nrw.de/luft/gerueche/bewertung.htm#1). Odour impacts are assessed as significant and legally not allowed if a frequency of odour perception of 10

% (general residential areas) or 15 % (village areas) of the yearly hours for an odour concentration of 1 OU/m³ is exceeded.

Ammonia may cause direct negative impacts on plants/trees at high concentration in the close range of stacks/outlets. Even more relevant is the **deposition of Nitrogen** in nitrogen-sensitive ecosystems and forest caused by ammonia emission that lead to eutrophication, acidification and Nitrate-leaching to ground and surface water. To avoid environmental impacts the additional concentration of ammonia caused by the construction and operation of an livestock installation should not exceed 3 µg/m^3 and the total concentration (background concentration plus additional concentration) should not exceed 10 µg/m^3 according to the so-called „Technical Instructions on Air Quality Control" (TA Luft) which is an administrative regulation. Assessment is based either on a distance regulation or on air dispersion modelling. If the immission limit values are exceeded a special-case examination is necessary.

Assessment of **N-deposition** is even more complex. Based on critical loads (CL) for sensitive ecosystems (e. g. 10-15 kg N ha^{-1} a^{-1} for deciduous and coniferous forest) special assessment levels are derived (e.g. 10-30 kg N ha^{-1} a^{-1}) depending on the status of protection (nature conservation) and/or function of an ecosystem (habitat, regulation or production) and environmental risk. An additional deposition of 5 kg N ha^{-1} a^{-1} caused by a livestock installation is usually assessed as not critical. On the other hand, in cases of very sensitive ecosystems according to the European Habitats Directive even lowest additional deposition loads (> 3 % of CL) are considered as critical in order to prevent deterioration of the ecological status.

Particulate emissions are associated with negative health effects for people/residents living in the surroundings of livestock installations in general. But there is increasingly concern about **bioaerosol-**associated health risk especially for sensible persons (immunocompromised people with certain diseases like diabetes, allergy sufferers, asthmatics). In order to limit health risk it is considered to prescribe the general application of air cleaners in the case of large livestock installations. In addition, assessment values for certain microorganisms (e.g. staphylococci, enterococci) in the range of 240 CFU/m^3 (= 3 x limit of quantification - 80 CFU/m^3) are discussed so that the (natural) background concentration is not significantly changed.

Emission of Nitrate and Phosphate to soil and water caused by excretion/manure is usually not a topic on the farm level (exception accidents and free-range systems for poultry). Emission to soil and water must be avoided by certain requirements for the construction and maintenance of installations for the collection and piping of liquid manure (channels, drains, pits, pipes, slide gates) and the storage of slurry and farmyard manure so that the best possible protection of water resources from contamination or other deleterious changes to their properties is achieved.
Best-practice procedures and constructional measures include e.g.

- use of impermeable concrete with high frost resistance,
- use of corrosion resistant material and sealed constructions,
- certification of the suitability of the seal at joint of the wall with the tank base,
- application of leak detection systems (circumferential drainage or even area drainage with control shaft) for underground tanks in general or storage tanks in water protection areas,
- regular inspection of the tank and ancillary installations,
- documentation of inspections and results in a farm journal,

- slurry lagoons are only permissible if they are lined with a double-layered plastic film with leakage control between and control shafts.

With respect to the application of manure requirements for the protection of water are set out in detail and made compulsory in the so-called “Fertiliser Application Ordinance” (Düngeverordnung) which is the implementation of the European Nitrates Directive. It is mandatory in the entire territory and covers fertilizer application, fertilizer rate calculation, and the establishment of nutrient balances.

Could you give a range of the level of emissions (if possible, with respect to the three main media, air, water and soil)? Can you supply values of EF used or cited, and the different units used in research or for the inventory and/or for declaration data?

Emission factors for air pollutants applied in Germany that are used for the assessment of livestock installations (permit procedures, environmental impact assessment) are published in the Guideline VDI 3894/1 “Emissions and immissions from animal husbandry - Housing systems and emissions - Pigs, cattle, poultry, horses“ 2011-09; see annex.
For water and soil data are not available.

Could you supply and rank the 3 key parameters influencing emissions you cite?

Odour

1. Animal category (species; pig/poultry/cattle fattening, pig breeding, egg production, milk production)
2. Housing system (manure removal system: deep-litter/slurry/manure belt system, ventilation system/airflow rate)

Ammonia

1. Animal category (species; pig/poultry/cattle fattening, pig breeding, egg production, milk production)
2. Feeding regime (protein level, phases)
3. Housing system (ventilation system/airflow rate, space provided, manure (removal) system)

Dust/bioaerosol

1. Animal category
2. Housing system (littered or not, animal activity)
3. Feeding regime (type and consistency of feedstuff, feed application)

What is your view on the agreement on livestock BAT Reference techniques to evaluate/compare new techniques enabling emission reduction (taking into account regional variation on EU climate/landform with respect to different levels of emission)?

See proposal from DE (informal TWG meeting, Brussels 25 February 2013):

Technical reference systems are needed for the different animal categories and stages of production (housing, manure treatment, storage and application) being in the scope of IED. It is

proposed to define low-level techniques as reference. If actual requirements and better practises are chosen as reference, achievable reduction efficiencies of different additional measures will be relatively small. The same approach has been chosen in the BREF ILF 2003 and in a new study conducted last year (Döhler et al., 2011): UN ECE-Convention on long-range transboundary air pollution – Task Force on Reactive Nitrogen - Systematic Cost-Benefit Analysis of Mitigation Measures for Agricultural Ammonia Emissions, Supporting National Costing Analysis. Umweltbundesamt (Federal Environmental Agency), Dessau.
http://www.umweltdaten.de/publikationen/fpdf-l/4207.pdf).

The reference systems must be described with respect to the environmental performance, operational data and economics.

A climatic differentiation of the reference system seems not necessary → restrictions can be taken into account under "applicability" of a BAT.

The following structure of reference systems is proposed:

Pigs	**Proposal for a reference technique**
- Waiting, mating, and gestating sows	Insulated, forced ventilated housings; partly slatted floor, single phase feeding
- Farrowing sows	Insulated, forced ventilated housings; crates, partly slatted floor, single phase feeding,
- Rearing of piglets	Insulated, forced ventilated housings; fully slatted floor, single phase feeding
- Fattening pigs	Insulated, forced ventilated housings; fully slatted floor, single phase feeding, slurry storage over the whole production period (123 days)
Poultry	
- Laying hens	Insulated, forced ventilated housings, litter based floor housing system (deep litter system with 1/3 of the total area as scratching area, 2/3 as deep pit with manure storage over the whole period - 393 days); **single phase feeding**
- Pullets (rearing of young hens)	See laying hens
- Broiler	Insulated, forced ventilated housings, litter based floor housing system
- Broiler breeder	Insulated, forced ventilated housings, litter based floor housing system
- Turkeys	Insulated, forced ventilated housings, litter based floor housing system
- Ducks	Insulated, forced ventilated housings, litter based floor housing system
Storage of manure	
- Liquid manure	Open storage, no covering
- Solid manure	Open storage (heap), no covering
Treatment of manure	
- Liquid manure	No treatment
- Solid manure	No treatment
Application	
- Liquid manure	Broadcast spreading without incorporation
- Solid manure	Broadcast dung spreading without incorporation

The proposal from the EIPPCB indicates that a differentiation according to different climate is not necessary in the case of ammonia. On the informal TWG-meeting (Brussels, 25 February 2013) it has been accepted not to take any regional variation into account. Restrictions of a technique due to climate conditions are a matter of applicability and shall be addressed to in chapter 4 and in the Conclusions.

Techniques of emission reduction available (whether BAT listed or not)
Which technique would you propose for which impact (air/soil/water)?

Technique[1)]	**Impact**		
	Odour[2)]	**Ammonia**	**Dust/bioaerosol**
Phase feeding, reduced protein level	0 (no clear correlation)	++ (positive effects over the whole production chain)	-
Adding fat to the feed	0	0	+
Deep litter system (pigs)	++	-	-
Floor design (convex sloped floor, separate functional areas; pigs)	0	+	0
Inlet air cooling (e.g. under-floor / geothermal heat exchanger)	0	+	0
Natural/free ventilation	0	+	0
Manure removal – belt system (anaerated/aerated)	+	++	0
Air cleaner	++ (only pigs; biogen odour concentration in the clean gas < 300 OU/m^3, no crude gas odour perceptible in the clean gas)	++ (removal efficiency 70 – 90 %)	+ Removal efficiency (+/- 90 %; from environmental hygiene point of view not sufficient)
Spraying of (rapseed)oil-water solution	0	0	+
Coverings (slurry storage)	++	++	-

1) See also: Annex - VDI 3894/2 - Emission factors for odour, ammonia and dust
2) odour reduction: only few techniques available that have a *significant* effect; in principle all techniques applied for ammonia reduction have a positive influence on odour, too

Do you think that it possible to rank the different environmental impacts? (e.g. quantity of NH_3 emissions against NO_3-emissions,…?)

Not in general; ranking could be possible if specific site conditions are taken into account (→ sensitivity of the environment at site).

What do you think is the level of knowledge of a given technique on the different impacts?

See table above

What do you think is the level of applicability of those techniques that you are familiar with (e.g. already used by farmer, only tested at the laboratory scale, or under scientific development)?

All techniques listed in the table above are already used by farmers; air cleaners are very effective for emission reduction at point of application (housings) but most costly.

What is the best unit(s) to evaluate the efficiency of a given technique (e.g. in terms of % reduction in N, absolute emission kgN $m^{-2}.j^{-1}$,…)?

Ammonia: kg NH_3 $year^{-1}$ per animal place, and kg NH_3 $year^{-1}$ per LU (housings)

Dust: g dust $year^{-1}$ per animal place, and g dust $year^{-1}$ per LU (housings)

Odour: OU_E s^{-1} per animal, and OU_E s^{-1} per LU (housings)

Related to m^{-2} s^{-1} in the case of area sources.

In addition in % reduction compared to a reference system (see above); this is often the only possibility to transfer results from one country to another.

Which parameters should be considered/measured in order to assess an abatement technique?

See VERA test protocols (http://www.veracert.eu/en/technology-manufacturers/test-protocols/)

What is level of precision (with respect to the reduction allocated to a given technique) that we can reliably expect (e.g. 50% reduction ±??%)?

30-50%

How can we control the efficiency of a BAT technique applied at the farm level? (e.g. VERA protocol or new EU ETV)?

Monitoring: a wide interpretation seems possible. This includes not only direct measurements (spot/short time/random measurements, continuous measurements) of emission, but also measurement and recording (electronic logbook) of parameters that are decisive for function (e.g. pH-level, pump-running times, energy/water consumption) or of specific technical provisions (e.g. thickness of a straw crust), type-approval etc.

VERA is only suitable for the verification of the function of a technique in order to provide certification (type approval) for it is too laborious/costly and needs specific expertise.

Which method of emission measurement should be used for which technique?

See VERA test protocols (http://www.veracert.eu/en/technology-manufacturers/test-protocols/)

What is the best way to show the reduction achieved by using a BAT technique? (level of reduction, cost, technical applicability, …)

In general: level of reduction compared to a reference system.

Reduction efficiency in relation to the whole production chain (e.g. application of combined techniques)

Cost per unit pollutant reduced (e.g. EUR per kg N)

Annex (on request)

VDI 3894/2 - Emission factors for odour, ammonia and dust

6. Gas Emissions Measurement Techniques for Livestock Building and Storage Facilities

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Measuring methods have to be chosen depending on the use of the results

During the animal production, approximately half of the mass input, i.e. feed and drinking water, is lost as gases. The majority of the gaseous emissions are considered as non polluting (carbon dioxide and water vapor) but polluting compounds are also emitted, e.g. ammonia, methane or nitrous oxide. In areas with large concentrated animal feeding operations these emissions can have local impacts on the environment (odours, eutrophication) (Hartung and Phillips, 1994; Schiffman, 1998) or more global impacts (global warming, acidification) (FAO, 2006). Since few years, these polluting emissions draw the interest of scientists but also stakeholders and policy makers. Various purposes motivate the quantification of gaseous emissions from livestock. Various methods have been developped to estimate these emissions. The measuring methods have to be adapted to the way the results are used.

Three different types of uses (Robin et al., 2010) of gaseous emissions are discussed here: (1) political or regulatory use, (2) scientific use, (3) certification use.

(1) Many countries all around the world with concentrated animal feeding operations engaged in policies of reduction of their pollutants gaseous emissions. For the agriculture, the targeted gases are ammonia and greenhouse gases (GHG = methane and nitrous oxide). In this context, the engaged countries have to provide annual national inventories. These national inventories are based on the use of emissions factors (EEA, 2009). For countries, who need to perform the accuracy (trueness and precision, BIPM, 2008a) of their inventories (Tier 2 or 3 method), there is a need to decrease the uncertainty on emissions factors and to have emission factors that are representative of the diversity of the animal production systems. This aim requires performing a high number of gaseous measurements with validated methods in order to cover the diversity of the situations of animal farms for each of the concerned gases. The screening of the emissions per types of farms will also allow the identification of the factors explaining repeated differences inside each category but also between the different categories of farms. For that purpose, standardized simplified methods based on spot measurements should be used. These methods (measurements, data processing, result reporting) should be easy and rapid to implement, low cost. Those who have been developed are based on spot measurements and models for interpolation (Dekock et al., 2009; Guingand et al., 2010; Hassouna et al., 2010b; Ponchant et al., 2008). Result reporting should give emissions per year taking into account farm productivity during the experiments and national averages (e.g. number of broiler batches per year, feed index and mortality in a meat poultry farm).

(2) The second purpose that motivates gaseous emissions quantification is the understanding of the emitting processes. Many scientists study the influencing parameters. Knowledge about these parameters can be included in models to simulate changes in livestock practices or the use of new techniques and to evaluate the impacts

of the changes at the farm level. Scientists are also implied in the development of measuring methods and devices. For these purposes, the monitoring of kinetics over the whole breeding period can be necessary to identify some crucial moments for spot measurements or to explain the emitting processes, the observations. Continuous measurements in laboratory or controlled conditions can ensure the reproducibility of results. Hypothesis of relationships between explanatory and dependent variables can be proposed at chosen time steps and well-defined systems. Result reporting should be as close as possible to observed system and period. Continuous but also intermittent measurements can be achieved in commercial conditions to ensure that the hypothesis remain valid when the diversity of farming systems, practices, or period length increase. The cost of these methods can increase when high requirements in technology or man work are associated to the methods.

(3) The last purpose is the certification use. The efficiency of mitigation techniques should be certified before application at national scale. In the context of the IPPC Directive 2010/75/UE, new installations for intensive rearing of poultry or pigs (with more than 40000 places for poultry, 2000 places for production pigs (over 30 kg), 750 places for sows) have to be equipped with one of the Best Available Techniques (BAT; IPPC, 2003) that should reduce ammonia emissions. This obligation concerns the means. However, the real efficiency of the mitigation technique can vary with the context, the implementation and time. Therefore, there is a need to propose standardized method to check the true emission factors that result after applying each of the BAT. The methods to quantify gaseous emissions in this context should be simplified methods so that the results are rapidly available. Low cost methods should be prefered so that more than 1 check-up could be done per year and per farm. Checking methods should also allow the quantification of different gases in order to be sure there is no pollution swapping. The accuracy (BIPM, 2008a) of the chosen measuring methods should be higher than the reduction target: e.g. if the reduction target of the BAT is 10%, the accuracy of measurements should be much better than 10%. In this case, results should be reported per year with a documented uncertainty estimated. The firms or researchers who developed new mitigation techniques should use similar kind of methods to evaluate and certify the performance of their products in different systems of animal production.

The measuring methods can be distinguished by some characteristics: number and diversity of measurements, duration and continuity of the measuring period, number and diversity of data and models required to report the final results from the raw observations. The measuring scale (time, space) is also an important characteristic of a method (local or global). Local methods are methods that require different kind of measurements inside the animal house or on the storage facilities (e.g. concentrations and air flow rate). These methods can be intrusive or non-intrusive. When it is intrusive, the user should consider the induced modifications during data processing and result analysis. When using intrusive methods, results can be far from the true value as shown by Hassouna et al. (2010a) and Balsari et al. (2007). Global methods are mainly non intrusive methods that provide emissions from the whole animal house or the whole storage facility thanks measurements achieved outside the source. Mass balance calculations can be considered as global intrusive methods when manure and feed sampling and weighing are necessary. These characteristics should be considered when choosing a measuring method as the implementation time and cost, and the measurement accuracy vary with the choice of the method, the size of the observed system, the length of the observed period and the measurement frequency.

Many possible measuring techniques can be adapted to each measuring method

The different characteristics of the measuring methods and the associated measurements allow the classification of the methods in 3 categories:

(1) Global intrusive methods: this category concerns mass balance calculations for volatile elements like C and N (Pollet et al., 1998). The mass balance relies on zootechnical and technical data concerning the animal house and the flock, models concerning body animal retention and sometimes literature data (for manure composition and feed composition when this information can not be measured for the flock). This method is simple to implement. However, it gives only N and C volatilization and neither the repartition between the different chemical species (NH_3_N, N_2O_N, N_2, CH_4_C and CO_2_C) nor the volatilization variations with time (e.g. nycthemeral variations due to climate and animal activity). Despite simplicity it can not be carried on in systems where the loss of mass is small compared to the uncertainty on the stock (e.g. 1 day emission in deep-litter systems) or on the input (e.g. water balance of herbivores grazing in permanent grasslands).

(2) Global non intrusive: this type regroups micrometeorological methods that associate concentration measurements with low detection levels and local or spatially distributed climate data. They are usually time-consuming and expensive (Hristov et al., 2011). Their use and accuracy is subjected to weather conditions (e.g. reverse modelling requires the wind in adequate direction or air sampling in positions all around the emitting site). Monitoring the gas emissions kinetics over whole breeding periods is a rather new challenge and has not been achieved in a several farms until the NAEM study (http://www.epa.gov/airquality/agmonitoring/data.html).

(3) Local (non intrusive or intrusive): this category concerns the most widely used measuring methods in animal houses. These methods require the quantification of gas concentrations (mainly gradients) and the air flow rate (sometimes just concentrations; Dore et al., 2004; Phillips et al., 2001; Phillips et al., 2000). Closed chamber (static or dynamic) often used to assess the emissions of slurry belong to this category (Balsari et al., 2007; Hassouna et al., 2010a; Rodhe et al., 2012).

Many methods are available to measure gas concentrations. They are characterized by the molecules they can detect, their detection limits, the measuring frequency, the precision, the costs and their ease of use. The choice of one method depends on the measuring purpose, the time and money budget and the emitting sources. Ni and Heber (2008) and Bunton et al.(2007) described the different measuring methods for ammonia concentration in livestock buildings. For GHG it is necessary to measure the concentrations in the background air and in the environment modified by the animals. When the gradients are small, the nycthemeral variations can also influence average emissions and biological regulations.

Whatever the targeted gas (ammonia or GHG), two types of measuring methods can be used: physical, chemical.

Optical methods include lasers, absorption spectroscopy. The main characteristic of these methods is that they are fast response, allow the monitoring of targeted gases kinetics and real time visualization of the data. The price of the measuring devices is high and the implementation of continuous measurements is time-consuming.

Chemical methods include chemiluminescence, Gas Phase Chromatography, acid traps, colorimetric tubes, passive badges, denuders. These methods are adapted to spot measurements (colorimetric tubes), or to average emissions (acid traps, denuders, passive badges). However, they can hardly be used to monitor concentration kinetics especially for a long period (as breeding period). Monitoring the variations in concentrations in real time is useful to adjust the measuring protocols or to identify specific processes and explain the observed variations. Most of these methods are selective (they provide the concentration of one gas despite the number of gases present in animal environments).

The evaluation of the cost of optical and chemical methods includes the cost of the measuring device but also the time spent for implementation, for data processing and result reporting, the cost of calibration (some device require daily calibration, other device can be only calibrated by the manufacturer), the cost of each gas concentration measurement. Even if chemical methods are easy of use, their costs can be high when the number of detected gases and the frequency of measurements increase.

The accuracy (trueness and precision, BIPM, 2008a) and the calibration drift given by manufacturer for all equipments of concentration measurement is variable and might not take into account specific gases present in the monitored site. When using these methods in livestock buildings, the specific conditions (ambiant air molecular composition, temperature, moisture, dust, animals) can induce bias that have not been anticipated and evaluated in laboratories conditions. These biases can affect the accuracy of concentrations measurements. If the measuring protocol has not been validated with the equipment used, the error on measurements can be high. For instance when an optical detection system that requires air sampling is placed outside the building, important bias can be due to condensation in the air sampling tube or to leakages between the sampling point and the measuring device. In this case, measured concentration with low-cost and robust methods allows to check the trueness of observed concentrations. When performing measurements in large buildings, gas concentrations inside the building can be heterogeneous. If the sampling points are not representative of emitting sources and heterogeneity of ventilation, the bias of gas concentration and emissions can be high even if a high precision device is used.

The assessment of airflow rates depends on the type of ventilation, either dynamic or natural. Anemometers can be used in low-pressure, dynamically ventilated barns, to measure the air flow rate of extracted air. In this case it is assumed that all the air entering the barn has a homogeneous concentration in all gases. As a matter of fact, this assumption can induce some bias when an unknown part of the air entering the barn flows close to a storage of manure or through another part livestock house. Godbout et al. (2012) present a review of the different sensors that can be used for ventilation rate assessment. Even when the sensors have a good accuracy, the airflow rate can be not accurate if the measurements were not validated on the measuring site with another method. The specific ambient conditions inside an animal house (dust, high moisture, ammonia, animal) can increase the calibration drift of the sensors (e.g. sensitivity of hot wire anemoters to dust).

For animal houses with natural ventilation the use of a tracing gas (Demmers et al., 2001; Samer et al., 2012; Samer et al., 2011; Schrade et al., 2012) is recommended. When using tracers such as SF_6 or He, this kind of method is too expensive to be implemented on a great number of houses. The accuracy of this method relies on the perfect mixing of the tracer gas and the homogeneity of concentrations and ventilation inside the barn (Shen et al., 2012; Van Buggenhout et al., 2009). Ventilation rates can also be predicted using the CO_2 produced by the animals and the manure or the associated heat productions (Blanes and Pedersen, 2005; CIGR, 2002. ; Pedersen et al., 1998; Phillips et al., 1998). Nevertheless, most heat production knowledge concerns animal productions in northern European countries and northern America. When the animal metabolism is different from those animals (growth rate, adult weight, heat or CO_2 production of manure, diurnal variations due to activity, etc.), the hypothesis of heat and CO_2 production will induce a bias in the ventilation estimates. Since few years, models developed with tools like CFD (Wu et al., 2012) are time-consuming but can help to improve the knowledge of ventilation and emission from animal houses.

A need for standardized and reference methods for measurement and uncertainty evaluation

As shown in the previous paragraphs, many different methods exist for the quantification of gaseous emissions from livestock. Nevertheless up to now there is no reference method with a known uncertainty that can be used to validate emission factor estimates, models of livestock emissions or the results of BAT in a large number of animal houses. References systems or sources have sometimes be proposed to evaluate methods but not in the case of emissions from livestock houses and manure storage. Their definition is a prerequisite to allow reproducibility evaluation and method or system comparison. The validation of measuring protocols also requires reference systems. This fundamental step also requires reference methods to confirm measured emissions. When making emission measurements in livestock building, obtained results can be far from or closed to the true emissions (the real emissions). Experiments made by Hassouna et al (2010a) with dynamic chambers on slurry storage facilities showed the necessity to carry on at least two methods to evaluate the range of true emissions. In this study, the emissions carried on with two different floating dynamic chambers were compared to the nitrogen and carbon mass balance deficits. The results show that the measured gaseous emissions explained between 21% and 61 % of the total nitrogen losses and between 86% and 103% of the total carbon losses. In this study the mass balance was considered as the reference method (i.e. closest to the true value). However, Espagnol et al (2012) showed that the mass balance is not always an appropriate reference method. The development of reference methods and systems is necessary but a long process. If we want to meet short-term needs for economical or social evolutions, combining few measuring methods, with associated uncertainties, is the best way to evaluate the range of true emissions. The question of uncertainty is central when implementing validation of methods. The evaluation of uncertainty is very complex regarding the measuring conditions and the variability of the breeding systems. This question must be treated now as the measuring methods are used for certification. Knowledge of uncertainty is also necessary to analyse results from literature. Differences on emissions between two systems can be discussed if we have an idea of the measuring uncertainty. Statistical differences between averages are not sufficient. The standard error on measurements is just a part of the uncertainty analysis. This analysis should take into account of all uncertainty sources identified as explained by BIPM (2008b). Each uncertainty source have to be quantified in laboratories or field conditions. Forgetting an important source of uncertainty induces focusing on the decrease of components of the total uncertainty that maybe minor. Method comparison and mass balance measurements can help to identify all sources of uncertainty.

There is currently no international standards for emission measurements as it is the case for mass or volume measurements. This situation induces the lack of critical information for literature analysis. For instance, differences in results from literature can be due to small differences in measuring equipment or protocol and not to the variability of emissions induced by differences between the breeding systems and climatic context. Hassouna et al. (2013) showed that the choice of the optical filters in photo-acoustic-spectrometry analyser plays a crucial role to minimize the influence of interferences of non targeted gases. This information is usually not given in published papers despite it can induce high differences between two analysers.

The standardization of measuring methods to quantify emissions from livestock is a long process that should be lead in successive steps: 1) the choice of the methods for various uses of results 2) the evaluation of the methods in reference systems and in various conditions 3) the writing of the measuring protocols and the recommendations 4) protocols for data processing and result reporting 5) protocols for uncertainty evaluation. It is obviously not possible to have universal protocols that could be applied in all breeding systems and in all pedo-climatic contexts. Detailed description of reference systems and comparison of results and uncertainties obtained from detailed protocols can help to understand observed differences and accelerate emission reduction from livestock houses and storage.

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7. The impact of livestock on the environment and technical solutions available in the United Kingdom

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A resume of the situation in the United Kingdom

UK ammonia emissions are dominated by those from cattle production. Table 1 below gives total UK emissions (kt NH_3) for 2011.

***Table 1**. UK ammonia emissions 2011 by major source*

Livestock production sector	kt NH_3
Dairy	71.3
Beef	57.6
Poultry	30.8
Pigs	17.6
Sheep	9.5
Other major source	
N Fertilizer	39.7

Within livestock production the largest sources of NH_3 emissions are buildings in which livestock are housed and following the application of manures to land (Table 2).

***Table 2**. UK ammonia emissions from livestock production 2011 by major source/activity*

Livestock production sector	kt NH_3
Housing	55.3
Hardstandings	21.7
Manure stores	31.0
Spreading	54.2
Grazing	28.6

In the UK grazing emissions account for only *c*. 15% of total emissions from livestock production despite over half of all excretal N being deposited on grazing land.

The greatest amount of NH_3 emitted from livestock buildings is from those housing cattle. In the UK buildings housing cattle are naturally-ventilated and of many different shapes and sizes.

Scientific knowledge : a short review on the impact of livestock on the environment (air, water, soil)

The environmental impacts of livestock farming systems and their long-term sustainability have been evaluated over the past 50 years with respect primarily to their impact on: air and water quality; potential impacts on human health; greenhouse gas (GHG) emissions and consequent impacts on ecosystem services and biodiversity.

1. Air quality and human health

Toxic and polluting gases, odours and particles are emitted as a result of livestock production. These include NH_3, hydrogen sulphide (H_2S), non-methane volatile organic compounds (NMVOCs), and particles contaminated with a wide range of microorganisms. Little is known about the health risks of exposure to these agents for people living in the surrounding areas. Malodour is one of the predominant concerns, and there is evidence that psychophysiologic changes may occur as a result of exposure to malodorous compounds. The production of aerosols by the reaction of NH_3 with other atmospheric pollutants (SOx and NOx) is also a health concern because it forms particles < 2.5 µm diameter ($PM_{2.5}$) that are harmful when inhaled (Barnard 1997). There is evidence that $PM_{2.5}$ concentrations in air have a linear, no-threshold effect on human health (Brunekreef and Holgate, 2002). Although NH_3 derived aerosols are only one source of $PM_{2.5}$, they are considered a major source, and agriculture contributes ~80% of the precursor NH_3.

2. Water quality

Generally accepted livestock manure management practices have been reported not to adequately or effectively protect water resources from contamination with excessive nutrients, microbial pathogens, and pharmaceuticals present in the manure (Burkholder et al., 2007). Anoxic conditions and extremely high concentrations of ammonium, total P, suspended solids and faecal coliform bacteria throughout the water column for approximately 30 km downstream from the point of entry have been documented as impacts of manure effluent spills from livestock units (Burkholder et al., 1997; Mallin et al., 2000).

3. Greenhouse gas emissions

In the UK, the livestock industry is a major source of methane (CH_4) emissions, mainly from enteric fermentation by ruminants, and is a source of nitrous oxide (N_2O) emissions, mainly from the applications of manures and fertilizer-N to land. Between 10 and 20% of agricultural GHG emissions arise from energy consuming activities on farm.

4. *Biodiversity*

Conversion of semi-natural habitats (e.g. grassland) to arable between 1940-1990, increased intensity of agricultural production and use of agro-chemicals has led to substantial increases in food production but has also to considerable loss of biodiversity and degradation of regulating, supporting and cultural services in the UK (Watson & Albon, 2010).

Key pressures identified by analysis of the causes of unfavourable condition and threats to habitats in the UK, from both SSSI and Biodiversity Action Plan data that are at least in part driven by agriculture include:

- Further habitat destruction and fragmentation.
- Nitrogen deposition.
- Water pollution from both point and wider (diffuse) sources.
- Water abstraction, drainage or inappropriate river management.

5. Other human health impacts and Antibiotic resistance

Gilchrist et al. (2006) raised concerns about the practice of co-locating pig and poultry facilities and the spectre of a global pandemic arising from new strains of avian influenza incubated in pigs and transmitted to humans.

The aggregation of thousands of animals at confinement operations has been accompanied by increases in the use of antibiotics and in some countries large cattle farms are twice as likely to administer antibiotics to animals in their feed and water. In some cases, producers use these drugs at low levels for therapeutic disease treatments (Matthews, 2000).

Which pollutants are of particular concern and why?

Nitrogen lost from the soil/crop system may cause various forms of pollution. Nitrate (NO_3^-) enters ground and surface waters (Foster et al., 1982). Ammonia (NH_3), when deposited to land, increases N eutrophication and soil acidification (Roeloffs and Houdijk, 1991). Nitrous oxide (N_2O) contributes to global warming (Bouwman, 1990) and breakdown of stratospheric ozone (Crutzen, 1981). Only emissions of dinitrogen (N_2) are environmentally benign.

Could you give a range of the level of emissions

I'm not sure that quoting a rage of emissions is of much help, since for some pollutants the range is considerable and may extend from little more than 0 to 100% of the N compound applied. For example, when livestock slurry or poultry manure are applied to sandy or shallow soils in late summer or early autumn all of the mineral N that remains in the soil following emissions of NH_3, N_2O and N_2 may be lost by leaching (e.g. Webb et al., 2001). Emissions of NH_3 have also been reported to be very variable following application to land (Thompson and Meisinger, 2004). However, these potentially very large, and very variable, ranges of loss of NO_3 and NH_3 contrast with the small emissions reported for N_2O, less than 3% of N applied and on average only around 1% of N applied.

Can you supply values of EF used or cited, and the different units used in research or for the inventory and/or for declaration data?

The greatest range of EF units is for emissions of NH_3 from buildings housing livestock which may be reported as g NH_3-N per hour, day or year per animal, per animal place, per livestock unit or per livestock heat unit. Ammonia emissions from livestock buildings may also be reported as % of N or TAN excreted. In contrast NH_3 emissions from manure stores are usually expressed as g/m^2 and sometimes per m^3 for solid manure stores or % of N or TAN put into the store. Emissions folowing application of anures to land are almost always expressed as % of N or TAN applied.

Could you supply and rank the 3 key parameters influencing emissions you cite?

The potential for maximum emission will be determined by the amount of TAN applied to the land. The three primary factors cited in the ALFAM report (Søgaard et al., 2002) were:

- TAN concentration
- Manure dry matter
- Soil moisture content

Although other workers have reported the greatest external influence on emissions following slurry application is solar radiation (e.g. Braschkat et al., 1997) which may be considered to drive temperature at the site of NH_3 volatilization, particularly in winter.

What is you view on the agreement on livestock BAT Reference techniques to evaluate/compare new techniques enabling emission reduction (taking into account regional variation on EU climate/landform with respect to different levels of emission)?

While the concept of a reference system with which to compare abatement techniques appears to be a useful concept, unless the abatement techniques are either tested within the reference system, or the reference system is part of a balanced study in which emissions from the abatement option are measured, it is difficult to draw robust conclusions about the efficiency of the abatement measure. For example, when testing reduced NH_3-emission techniques for the application of manures it is relatively simple to have a treatment in which manure is applied to the surface and left there. Such a comparison is much more difficult when testing new housing systems or store covers on commercial farms, since a 'control' will not be available and making comparisoon with a neighbouring farm or manure store introduces random variables. This effect is compounded when applying the findings of a reduced emission system introduced in one part of Europe with current systems in another part of Europe.

Techniques of emission reduction available (whether BAT listed or not)

Slurry

- Application to tillage or grassland by open slot injection.
- Application to grassland by trailing shoe.
- Application to growing crops by trailing hose.
- Incorporation into tillage land by plough within 4 h of application.
- Incorporation into tillage land by disc or other non-inversion technique within 4 h of application.
- Incorporation into tillage land > 4 h after application.

Solid manure

- Incorporation into tillage land by plough within 4 h of application.
- Incorporation into tillage land by disc or other non-inversion technique within 4 h of application.
- Incorporation into tillage land > 4 h after application.

Which technique would you propose for which impact (air/soil/water)?

The impacts of each technique on emissions of NH_3 and other pollutants are tabulated below.

***Table 3**. Impacts of reduced-ammonia manure spreading techniques on emissions of ammonia, nitrous oxide and nitrate leaching*

	Ammonia	Nitrous oxide	Nitrate
Slurry			
Open slot injection	----	+	0, leaching depends on timing
Trailing shoe	---/		0, leaching depends on timing
Trailing hose	--	+	0, leaching depends on timing
Plough within 4 h	-----		0, leaching depends on timing
Non-inversion within 4 h			0, leaching depends on timing
Solid manure			
Plough within 4 h	-----	-	0, leaching depends on timing
Non-inversion within 4 h	---		0, leaching depends on timing
Plough within > 4 h	---		0, leaching depends on timing

- indicates decrease in emission
+ indicates increase in emission

The suitability of a technique should be determined by its effectiveness in reducing emissions of NH_3. Nitrate leaching can be controlled by appropriate timing of manure application. The method will have no significant impact. The effects on emissions of N_2O are less certain (Webb et al., 2010 and references cited therein) but due to the reduction of indirect emissions of N_2O following effective reduction of NH_3 emissions there is unlikely to be any net increase in N_2O emissions from using the most effective means of NH_3 abatement.

Do you think that it possible to rank the different environmental impacts? (e.g.; quantity of NH_3 emissions against NO_3 - emissions,…?)

The environmental impacts may be ranked by means of the estimated costs to society of each form of pollution. Webb et al. (2007) ranked the environmental impacts of pollutant N in the order (of decreasing environmental impact) N_2O-N > NH_3-N > NO_3-N. More recent work is reported by van Grinsven et al., (2011) and takes into account impacts of human health due to inhalation of fine particles (aerosols).

What do you think is the level of knowledge of a given technique on the different impacts?

An estimation of our current understanding of the major reduced-NH_3 emission techniques is summarized above.

What do you think is the level of applicability of those techniques that you are familiar with (e.g.: already used by farmer, only tested at the laboratory scale, or under scientific development)?

The UK Inventory (Misselbrook et al., 2012) provides current estimates of the extent to which reduced-NH_3 emission techniques have been adopted in the UK.

Table 4. Proportions of manures applied by reduced-ammonia emission techniques in the UK

Technique	% of manure applied
Cattle slurry applied to grassland and arable by shallow injection	1
Pig slurry applied to grassland and arable by shallow injection	11
Cattle and pig slurry applied to grassland and arable by trailing shoe	0
Cattle slurry applied to grassland by trailing hose	3
Pig slurry applied to grassland by trailing hose	19
Cattle slurry applied to arable land by trailing hose	3
Pig slurry applied to arable land by trailing hose	15
Cattle and pig slurry, applied to arable, incorporated within 6 h	6
Cattle and pig slurry, applied to arable, incorporated within 24 h	19
Cattle and pig FYM, applied to arable, incorporated within 4 h	3
Poultry manure, applied to arable, incorporated within 4 h	8
Cattle FYM, applied to arable, incorporated within 24 h	18
Pig FYM, applied to arable, incorporated within 24 h	26
Poultry manure, applied to arable, incorporated within 24 h	46

What is the best unit(s) to evaluate the efficiency of a given technique (e.g.: in terms of %reduction in N, absolute emission kgN.m-2.j-1,…)?

To evaluate the efficiency of a given abatement technique the most appropriate unit to allow comparisons of efficiency is as a proportion or percentage of the unabated emission. To state that an abatement technique reduces emissions by x kg/ha or y kg/m^2 is to assume baseline emissions are uniform, which they will not be. If an abtement efficiency is expressed as an absolute amount then that amount might exceed the baseline emission in many circumstances. It may be the case that abatement efficiencies are not a fixed proportion of baseline emissions and that the efficiency of a technique may increase or decrease with increasing baseline emissions. However, if that is the case then this may be explained and a relationship reported along with the average abatement efficiency.

Which parameters should be considered/measured in order to assess an abatement technique?

The key parameter to be measured will be emissions of NH_3. However, in order to assess the impact of NH_3 abatement on other polluting forms of N loss it is desirable to also measure emissions of N_2O and either measure or model nitrate leaching. Ideally uptake of manure-N should also be measured to indicate the extent to which the NH_3-N conserved is recovered by the crop hence increasing th value of manure as a N fertilizer. The costs of the technique also need to be estimated and recorded in order to asses the cost of the technique in comparison with surface application and to assess the extent to which any additional costs are offset by the increased manure-N value.

What is level of precision (with respect to the reduction allocated to a given technique) that we can reliably expect (e.g.: 50% reduction ±??%)?

Webb et al. (2010) reported considerable variation in measured abatement efficiencies from reduced NH_3 emission application techniques (Table 1).

***Table 5**. Summary of results of experiments to measure the abatement efficiency of reduced-emission slurry spreading machinery, % reduction in NH_3 emissions compared with broadcasting to surface. The range is the range of the means reported in each paper considered.*

Machine	Cropping	Papers	Experiments	Mean % reduction		Range (%)
				Overall	Weighted	
Slot Injec.	Grass	5	56	80	86	60-99
	Tillage	5	9	70	49	23-94
Deep Injec	Tillage	2	5	95	97	95-99
Trail shoe	Grass	3	30	67	68	57-74
Trail shoe	Tillage	2	2	64	64	38-90*
Trail hose	Grass	5	49	26	29	0-30
Trail hose	Tillage	7	16	37	48	0-75

*this result was obtained from a machine that placed the slurry within the soil

Nevertheless, it was possible, using a simple one-way ANOVA, to conclude that some slurry application techniques were significantly more effective than others Table 2 provides means and ranges as ±1 Standard Deviation.

***Table 6**. Possible means with ranges of abatement efficiencies, expressed as % reduction of unabated emissions,.*

Machine	Mean % reduction		
	Trail hose	Trail shoe	Slot Injec.
Grass	35 (30-40)	65 (50-80)	80 (60-100)
Arable	35 (30-40)	NA	70 (50-90)

There was less variation among the results of rapid incorporation trials, albeit there were generally fewer trials carried out (Table 3)

Which method of emission measurement should be used for which technique?

This document only includes techniques to reduce emissions of NH_3 following application of livestock manures to land. Currently the default NH_3 emissions following the application of manures to land, as reported in the UKAEI, have been derived only from the average of measurements made using micrometeorological mass balance techniques and omitting the results obtained with wind tunnels. This change was introduced because measurements obtained using wind tunnels tend to over-estimate absolute emissions of NH_3, although they are considered satisfactory for use in comparative studies, e.g. of abatement techniques (Loubet et al., 1999a, b).

***Table 7**. Summary of results of experiments to measure the abatement efficiency of incorporating manures, % reduction in NH_3 emissions compared with broadcasting to surface. The range is the range of the means reported in each paper.*

Machine	Manure	Papers	Experiments	Mean	Weighted mean	Range
Plough	Slurry	3	8	92	94	78-99
Disc	Slurry	2	12	80	74	69-90
Tine	Slurry	1	12	66	68	
Harrow	Slurry	2	3	68	69	60-69
Plough	FYM	3	9	91	92	86-95
Disc	FYM	1	5	63		
Tine	FYM	1	5	57		
Harrow	FYM	1	1	90		

What is the best way to show the reduction achieved by using a BAT technique? (level of reduction, cost, technical applicability, …)

I would suggest the best way to show the reduction achieved using a BAT techniques is as a result of replicated measurements carried out on commercial farms which demonstrate significant reductions, not just in the statistical sense, but also large enough to make measurable differences to the N content of livestock manures and their value as N fertilizers.

About the author

J Webb is internationally recognised as one of Europe's leading experts on ammonia emissions from agriculture and the means of reducing them and has been consulted on the topic by Defra, the Environment Agency, the EU Commission, the UN Task Force on Reactive Nitrogen and the US Environment Protection Agency. He is currently co-Chair of the European Gaseous Emissions Research Network and was formerly Chair of the UN Expert Group on Ammonia Abatement. He was responsible for developing the NARSES model which is currently used to calculate national emissions of ammonia for the UK Atmospheric Emissions Inventory. The mass flow approach developed for the NARSES model has been adopted as the basis for ammonia emissions inventories in several NW European countries and Canada, and the methodology is now used in the EEA/CORINAIR Guidebook. He has managed *c*. 10 major collaborative research projects on ammonia. Of particular relevance to this proposal, in addition to his creation and validation of the NARSES model, is work undertaken for the Environment Agency to assess the extent to which EFs could be determined for discrete housing systems. He has also reviewed the research database from which current UK EFs were prepared on behalf of Defra and the British Pig Executive (BPEX) and made recommendations for future research to fill the most significant gaps. He has also lead projects to measure ammonia emissions from buildings housing livestock. He has published 24 papers on ammonia emission in peer-reviewed journals. He Peer-reviewed the Canadian Ammonia Emissions Inventory (NAESI) and updated the agriculture chapters in the EMEP/CORINAIR Guidebook of Emission Inventories.

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8. Cattle housing

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Cattle housing systems across Europe

A variety of housing types exist across Europe for dairy and beef production systems, but these can be broadly categorised as either slurry-based or solid manure-based systems. Most systems are naturally ventilated. In some countries, the housing may also be associated with some outdoor yard areas for cattle exercise, collection or feeding. The proportion of the year that the housing is occupied by the cattle will vary according to local climate and production system (e.g. proportion of time spent by the animals at grazing).

Dairy housing systems may consist of cubicles with a solid floor passage, which would be scraped regularly to remove manure (as slurry); cubicles with a slatted floor passage, where slurry would be collected beneath the slats; deep litter bedded solid floor housing without cubicles, where solid manure accumulates for several months; or (much less common) tied-stall systems, where slurry and/or solid manure are removed regularly from channels behind the animal standing area. Slurry systems predominate for dairy production, particularly for newer, larger installations.
Beef cattle housing systems may consist of fully slatted floors, with slurry accumulation beneath the slats, or deep litter bedded floors with solid manure accumulation over several months. In much of Europe slatted-floor slurry systems predominate, particularly in countries such as Ireland where bedding materials are not readily available, whereas in other countries (e.g. England) solid manure systems are most common.

Main impacts of cattle housing on the environment

Cattle housing should not pose a pollution risk to water bodies, although run-off water from outdoor yards may do so if not properly contained. Of more importance are gaseous emissions to the environment, particularly ammonia, but potential also for the greenhouse gases methane and nitrous oxide, nitric oxide and non-methane volatile organic compounds. Methane emissions arising from enteric fermentation by the cattle are not considered here as they are not influenced by the housing system, but rather by factors such as diet and productivity which are considered elsewhere. Slurry coated concrete surfaces are generally insignificant sources of methane and nitrous oxide (e.g. Webb et al., 2001; Pereira et al., 2011). Solid manure accumulating within cattle houses will be a larger source of methane and nitrous oxide (Chadwick et al., 2011) but still of small significance compared with the major sources of these gases (enteric fermentation and microbial processes within soils for methane and nitrous oxide, respectively). Few data exist on emissions of nitric oxide or non-methane volatile organic compounds from agricultural sources, but cattle housing is not likely to represent a significant source of these gases either.

The major gaseous emission of concern from cattle housing systems is therefore ammonia, and this will represent the focus of the remainder of this paper. In comparison exercises of national inventory models for ammonia emissions from agriculture, typical emission factors, expressed as a percentage of total ammoniacal N (TAN) excreted in the house, were in the range 15 – 31% and 12 – 37% for dairy cubicle and beef deep litter systems, respectively (Table 1). Taking into account national differences in N excretion, these values approximated to emissions per animal place of 10–20 kg and 3.5-8.5 kg for the dairy and beef systems, respectively. Sommer et al. (2006) suggest typical emission factors at the lower end of these ranges, citing 6% of TAN for tie stall systems, 12-17% of TAN for cubicle houses and 12% of TAN for deep litter systems. Most reported measurements are for NW European countries; the few data from southern Europe suggest emission factors at the higher end of the range for those countries (e.g. Pereira et al., 2010), as might be expected.

Table 1: *Cattle housing emission factors (% TAN) for some European countries*

Country	Dairy cow cubicle house[a]	Beef cattle deep litter house[b]
Denmark	17	12
Germany	20	20
Netherlands	15	17
UK	31	23
Switzerland	17	37

[a]Reidy et al., 2008; [b]Reidy et al., 2009

Emissions from outdoor yards associated with cattle housing can be very significant, depending on the frequency and effectiveness of excreta removal from the concrete surface. Misselbrook et al. (2006) reported mean emission rates of 0.47 and 0.98 g NH_3-N animal^{-1} h^{-1} for UK yards used by dairy and beef cattle, respectively, the higher value reflecting the much larger yard areas associated with beef cattle yards.

The major factors influencing emissions from cattle housing are the size of the emitting surface (i.e. the extent of the fouled floor area), the strength of the emitting source (largely influenced by dietary impacts on urine N excretion) and the resistance to ammonia transfer from the emitting surface. This latter will be largely influenced by air flow across the emitting surface and temperature, and hence for naturally ventilated systems by local climatic conditions. For deep litter systems, the transfer coefficient will also be influenced by the litter moisture content and the surface roughness of the emitting surface. Theoretical considerations would dictate that emissions will increase for increasing surface area, source strength, air flow and temperature (e.g. Sommer et al., 2006).

Techniques for emission reduction

There has perhaps been less emphasis on reduction technologies for cattle housing that for intensive pig and poultry housing, where advances have been driven by the IPCC Directive. However, a range of potential options do exist, although most of these are listed as Category 2 or 3 techniques in the UNECE Guidance Document for abating agricultural ammonia emissions. Extending the outdoor grazing period, thereby reducing the time and quantity of excreta that cattle deposit in the house, is a potential option, provided that land conditions are suitable. Ammonia emissions from urine deposition at pasture are much lower than housing emissions, but there may be trade-offs with increased nitrous oxide emission and nitrate leaching from urine patches.

Slurry systems

For dairy cow cubicle houses and associated outdoor concrete yards, emission reduction techniques rely mostly on reducing the size of the emitting area and rapid removal of excreta from concrete surfaces.

Misselbrook et al. (2006) showed that on a per animal basis, emissions were much lower (40-50%) from an outdoor concrete yard at a higher given stocking density. Minimising of floor and yard areas that are used by cattle, with welfare considerations being taken into account, can therefore be very effective at reducing emissions. This may be particularly relevant where animals are spending periods at grazing, during which time there may be opportunity to minimise access to certain areas within the house.

Scraping of floors and yards to remove excreta is not necessarily effective at reducing emissions, as a layer of excreta will often remain on the floor surface and continue to emit. However, scraping systems combined with improved floor design, such as grooves or sloping floors to facilitate rapid urine removal to slurry storage, can be effective (up to 40% reduction in emission; Swiestra et al., 2001). For slatted systems, fitting of rubber flaps between the slats will reduce emissions from the below slat slurry storage area through a reduction in the air exchange, but any reductions may be partially offset by excreta fouling the upper surface of the rubber flaps.

Large reductions in emission can be achieved through washing down fouled surfaces with water (Misselbrook et al. (2006) reported c. 90% reduction), but additional labour requirements and water use represent additional costs. In-house flushing systems (using water, acid, diluted or separated slurry) have so far proved to be ineffective or difficult to maintain.

Spraying of urease inhibitors to floors and yard surfaces is a potentially effective measure; Misselbrook et al. (2006) reported emission reductions of 55-65% for daily applications of a urease inhibitor to an outdoor yard used by cattle. Further development and testing of this potential measure is required to determine appropriate rates and frequencies of application, practicalities and costs.

Deep litter systems

Minimising fouled surface areas is also important for litter based housing systems. However, probably of more importance for these systems is litter management and, in particular, keeping the litter surface as dry as possible. Use of additional straw bedding (above typical rates used), and in particular targeting the additional bedding to dirtier areas such as around feed barriers or water troughs, can give emissions reductions up to 50% (Gilhespy et al., 2009), but will be associated with costs for the additional bedding used and an increased volume of manure to be managed when removed from the house. Different bedding materials can be associated with different emission rates (e.g. Misselbrook and Powell, 2005), but wider considerations of animal health and welfare and ease of management of the material need to be taken into account. In practice, availability of a material locally will be an important factor determining use.

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9. Emissions of ammonia, nitrous oxide and methane from pig houses: Influencing factors and mitigation techniques

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Introduction

Pork is currently the most widely consumed meat product in the world, accounting for 38% of total meat consumption. By 2050, worldwide pig consumption is expected to increase by 40% owing to the demographic growth, the changes in food preferences and the agricultural intensification (FAO, 2011). The impact of livestock production on the environment is attracting increasing attention, especially the effects on pollutant gases like ammonia and greenhouse gas emissions, i.e. carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Globally, livestock production accounts for 64% of ammonia emissions and 18% of anthropogenic emissions of cumulated greenhouse gases (FAO, 2006). Pig sector contribute to about 15% of livestock related emissions (Olivier et al., 1998; FAO, 2006 and 2011).

The aim of this paper is to describe the factors that impact NH_3, N_2O and CH_4 emissions from pig buildings and to identify some mitigation techniques regarding housing conditions. The effects of feeding strategies will not be addressed in this work whereas they constitute interesting options for reduction.

Sources of ammonia, nitrous oxide and methane from pig houses

The main source of NH_3 is the rapid hydrolysis of urea of urine by the urease leading to ammonium (NH_4^+) (Cortus et al., 2008). Another source of NH_3 is the degradation of undigested proteins, but this pathway is slow and of secondary importance (Zeeman, 1991). The urease is a cytoplasmic enzyme largely present in faecal bacteria (Mobley and Hausinger, 1989). In livestock buildings, it is present in abundance on fouled surfaces like floors, pits and walls (Ni et al., 1999). Urease activity is affected by temperature with low activity below 5–10℃ and above 60℃ (Sommer et al., 2006). Under practical conditions, models show an exponential increase of urease activity related to temperature (Braam et al., 1997). Urease activity is also affected by pH with optimum ranging from 6 to 9, while animal manure pH is usually buffered to between 7.0 and 8.4. Therefore, optimal conditions for complete urea hydrolysis are largely met in animal husbandry, making the urea availability the limiting factor. The NH_4^+ production depends also on manure moisture content because water is necessary for bacterial activity (Groot Koerkamp, 1994). Thus, NH_4^+ production is optimal between 40% and 60% moisture content but releases decrease at values above and below this range. Ammonia production stops below 5–10% moisture content (Elliot and Collins, 1983).

The formation of N_2O occurs during incomplete nitrification/denitrification processes that normally convert NH_3 into non-polluting N_2. During nitrification, N_2O can be synthesized where there is a lack of oxygen and/or a nitrite accumulation. During denitrification, N_2O is synthesized in the presence of oxygen and/or low availability of degradable carbohydrates (Poth and Focht, 1985; Driemer and Van den Weghe, 1997). In addition, N_2O can be formed during other microbial pathways: aerobic or anaerobic ammonium oxidation (so-called nitrifier denitrification and anamox, respectively). Most of nitrifying and denitrifying microorganisms are not thermophilic and thus the N_2O formation is inhibited by temperature above 40-50℃. Finally, N_2O can be produced during an abiotic ammonium conversion under acidic conditions (so-called chemodenitrification) (Oenema et al., 2005; Petersen et al., 2006). The relative contribution of these various pathways has to be still determined. Anyway, N_2O synthesis needs close combination of aerobic and anaerobic areas. These heterogeneous conditions are not met within slurry but litter. However, N_2O emissions can occur from slurry when a dry crust is formed on the surface with combination of anaerobic and aerobic micro-sites. Because of these numerous sources and environmental controls, N_2O production from manure has a highly stochastic nature, especially with litter systems.

Methane production is slightly less complex. It originates from the anaerobic degradation of organic matter performed by mesophilic/thermophilic bacteria with an optimal pH close to neutrality (Hellmann et al., 1997; El-Mashad et al., 2004). In piggery, the sources of CH_4-emissions are the animal digestive tract and the releases from the waste. The level of enteric CH_4 is function of the fermentative capacity of the hindgut and the content, source and solubility of dietary fibre (Philippe et al., 2008). In manure, CH_4-release is promoted by high temperature, high organic matter content and anaerobic conditions (Amon et al., 2006). On contrary, the production is inhibited under aerobic conditions or high concentration of ammonium and sulphides (Monteny et al., 2006). If a surface crust is formed on slurry, CH_4 produced within the manure can be oxidized into CO2 during passage through the crust with less CH_4 releases as consequence (Petersen et al., 2006).

Influencing factors

Climatic conditions

Emissions of pollutant gases are positively related to ambient temperature and ventilation rate thanks to effects on physical, chemical and microbiological processes.

For example, when ambient temperature increased from 17 to 28℃, NH_3 emissions increased from 12.8 to 14.6 g NH_3/pig.day (Granier et al., 1996). When ventilation rate increased from 9.3 to 25.7 m^3/h.pig, NH_3 emissions increased by 25% (Granier et al., 1996). However, it is important to notice that temperature and ventilation are interlinked as seen elevate flow decreases air temperature. The ventilation type and the location of the fans also contribute to modulate the emissions. Air inlets or outlets located near the manure surface increase the emissions consequently to higher air exchange rate at interface (Hayes et al.,2006). Nevertheless, the ambient parameters must primarily respect the bioclimatic comfort of the animals. Moreover, the climatic conditions may alter the pig behavior with indirect effects on emissions. Thus, the control of ambient parameters especially under hot conditions, has to encourage the pigs to foul the excretory area and to remain clean and dry the lying and exercise areas (see below).

Floor type, pen design and manure management

In pig production, the main housing systems are based on slatted floor or bedded floor. Within both floor types, a large range of techniques were developed in order to reduce the environmental impact of pig production.

Slatted floor systems

Most of the pigs are kept on concrete slatted floors with a deep pit underneath for the storage of the slurry for long periods (several months). This so-called “deep-pit” system is usually considered as reference technique.

Good drainage of manure through the slatted floor limits fouled areas that are significant sources of NH_3 (Svennerstedt, 1999). Drainage properties of the floor are influenced by material characteristics, slat design and width of openings. Concrete characteristics, such as roughness and porosity, impact NH_3 production, with lower NH_3 emissions with smooth floors (Braam and Swierstra, 1999). In the same way, substituting concrete slats by cast iron, metal or plastic slats can reduce NH_3 production by 10 to 40 % (Pedersen and Ravn, 2008). The profile of the slats has to be designed in order to avoid manure lodging between slats. Thus, trapezoidal cross section favours manure drainage, with better results from protruding (Svennerstedt, 1999) or sharp edges (Ye et al., 2007; Hamelin et al., 2010). Increasing opening size is also a good means of facilitating drainage and limiting NH_3 production. Under laboratory conditions, enlarging gap widths, from 2 to 30 mm, decreases emission by more than 50% (Svennerstedt, 1999). Besides traditional rectangular openings, round or semi-circular openings may be used, but with increased risk of clogging, greater fouled area and greater emissions (Svennerstedt, 1999). The effects of slat characteristics on N_2O and CH_4-emissions were very few studied. However, it can be assumed that they are of little importance, considering the formation process of these gases.

Reducing the emitting slurry surface is commonly used to decrease the emissions. Thus, partly slatted floor systems with reduced slurry pit area is known to produce lower levels of NH_3 compared to fully slatted floor systems, as confirmed by numerous studies. For example, in the experiments of Sun et al. (2008) with fattening pigs, NH_3 emission factors are reduced by about 40% by replacing fully slatted floors by partially slatted floors (37% of pen floor area). Decreasing slatted floor area from 50% to 25% of total area shifts daily emissions from 6.4 to 5.7 g NH_3 per fattening pig (Aarnink et al., 1996). On the contrary, some authors reported similar emissions whatever the proportion of slatted floor (Guingand and Granier, 2001; Philippe et al., 2012a). By reducing the slatted floor by 50%, Philippe et al. (2012a) did not measured significant difference for NH_3, N_2O and CH_4 emissions. Moreover, higher emissions have been observed for gestating sows on partly slatted floor with NH_3, N_2O and CH_4 emissions increased by 24, 11 and 17%, respectively (Philippe et al., 2010a). According to Guingand and Granier (2001), NH_3 emissions during summer time were increased by about 80% with partially slatted floor (50% of pen floor area). Actually, the excretory behaviour of the pigs that tend to foul the solid area under specific conditions like hot temperature or high animal density fails to reduce emissions with partly slatted floor. The installation of a sprinkler to cool the animals or sufficient available space area could prevent increasing of emissions. Moreover, designing housing conditions that respect the natural excretory/lying behaviour of the pig may contributes to limited emissions. Most of the pigs urinate and defecate in the free corner of the pen, away from the feeder or drinker (Aarnink et al., 1996), indicating where the slats have to be placed. The pen partition type also impacts on the dunging location. Closed pen partitions reduce air drafts, keep the sleeping area warmer and maintain a temperature gradient between the warmer lying area and the cooler dunging area. With open pen partitions, pigs are inclined to urinate and defecate in the boundary area (Hacker et al., 1994). The slat material can influence the excretory behaviour of the pigs. For example, in a partially slatted pen, a metal slatted floor with triangular section and metal studs was especially developed to create a fixed dunging place, by preventing the pigs from lying in the area with studs (Aarnink et al., 1997).

Reducing the emitting manure surface can also be achieved by modification of the pit design, principally thanks to sloped pit walls or manure gutters. Doorn et al. (2002) reported a reduction of NH_3 emissions by 28% for fattening pigs while the emitting surface was also reduced by 28%. Similar results were observed with weaned piglets (van Zeeland and den Brok, 1998) and gestating sows (Timmerman et al., 2003).

Frequent manure removal can also be proposed as a mean to diminish the emissions from the building. Total emissions including storage will be reduced provided lower outside temperature than inside or specific manure treatments. A fortnightly removal reduced NH_3 emissions by 20% compared to a system where the slurry was stored for the duration of the finishing period (Guingand, 2000). A weekly discharge reduced NH_3 as well as N_2O and CH_4 emissions by about 10% compared to the traditional deep-pit system (Osada et al., 1998). With the same removal strategy, Guarino et al. (2003) observed NH_3 and CH_4 emissions reduced by 38 and 19%, respectively, but N_2O emissions were doubled.

Pit flushing is also an efficient mean to reduce emissions. Significant reduction by 45% for NH_3 and 49% for CH_4 were observed with this technique compared to static pits (Lim et al;, 2004; Sommer et al., 2004). In association with manure gutters or flushing tube incorporated into the concrete slat, Lagadec et al. (2012) measured NH_3 and N_2O emissions reduced by 5 to 20%. Frequency, duration and pressure of the flushing water also impacted on the efficiency of mitigations (Kroodsma et al., 1993; Misselbrook et al., 2006). For example, frequent flushing (every 1-2 h) for short periods (2 seconds) is more effective than prolonged (3-6 seconds) but less frequent flushing (every 3.5 h) (Kroodsma et al., 1993). The use of fresh water, as opposed to recycled water, further reduces emissions. This is especially the case for CH_4 because methanogenesis is rapidly initiated in the channel if small part of slurry remains in the pit after emptying whereas, without inoculums in the pit, CH_4 formation is low and initiated after few days (Sommer et al., 2007).

The manure can also be removed by scraping. Standard flat scraper systems consist 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 (Groensetein, 1994). However, this type of manure removal seems to have no positive effect on NH_3 emissions (Predicala et al., 2007; Kim et al., 2008a; Lagadec et al., 2012). Indeed, the surface under the slat is always soiled because the scraping spreads faeces and urine over the pit and the small film left on it creates a greater emitting area.

In contrast, the V-shaped scraper system is effective in reducing emissions since it is associated with separation of urine from faeces. This system involves a channel with two inclined surfaces on each side of a central gutter. Thanks to a longitudinal slope of around 1%, the liquid fraction continuously runs off by gravity towards the gutter before being redirected outside the building. The solid fraction remains on the inclined surface before being scraped several times a day (Godbout et al., 2006). By the installation of an under-slat V-shaped scraper, reductions around 40-50% were achieved for NH_3 and N_2O, and around 20% for CH_4 (Godbout et al., 2006; Lagadec et al., 2012).

Conveyor belts are also an effective system to separate urine from faeces under slats. They are composed of a perforated belt through which the liquid percolates into a conventional pit whereas the faeces left on the belt are conveyed out of the pen into a separate collection pit (Lachance et al., 2005; Pouliot et al., 2006). With this system, authors reported reductions of NH_3- and CH_4-emissions around 50% and 20%, respectively, in comparison with conventional storage systems (van Kempen et al., 2003; Godbout et al., 2006). These techniques seem also advantageous because the separation facilitates recycling and treatment of manure, reduces storage requirements and transportation costs, and offers more homogenous materials for land spreading.

Bedded systems

For the past few decades, bedded systems have met renewed interest, as they are related to improved welfare, reduced odour nuisance and a better brand image of livestock production. However, this technique is associated with increased cost principally due to the straw use and the labour for litter management even if building costs are usually reduced (Philippe et al., 2006). For existing buildings, this system can be quite easily applied for housing with concrete solid floor.

Comparisons between bedded systems and traditional slatted floor systems show contradictory results regarding NH_3 and CH_4 emissions while N_2O emissions were systematically increased with the former but presenting large variation between studies (Philippe et al., 2007a, 2007b and 2011). These discrepancies can be explained by the wide range of rearing techniques of pigs on litter: the litter substrate, the amount of supplied litter, the space allowance and the litter management. These parameters influence the physical structure (density, humidity) and the chemical properties of the litter that interact to modulate gas emission levels (Dewes, 1996; Groenestein and Van Faassen, 1996; Misselbrook and Powell, 2005).

Several bedding materials were tested in regards to emissions. The most frequent substrates are straw and sawdust. Compared to straw litters, sawdust litters produce less NH_3 and CH_4 but more N_2O (Nicks et al., 2003 and 2004; Cabaraux et al., 2009). By instance, the raising of five successive batches of weaned piglets on the same sawdust litter, reduced the NH_3 emissions by 62% (0.46 vs. 1.21 g NH_3/pig.day) and the CH_4 emissions by 49% (0.77 vs. 1.58 g CH_4/pig.day), but 4-fold N_2O emissions (1.39 vs. 0.36 g N_2O/pig.day), compared to straw litter (Nicks et al., 2004). Higher manure density observed with sawdust may impair composting process, which normally increases the manure temperature and air exchange through it. Consequently, NH_3 emissions are reduced, which increases the amount of ammonium available for non-thermopilic nitrifying bacteria, with higher N_2O emissions as consequence (Sommer, 2001; Hansen et al., 2006). Moreover, lower temperatures inside the litter diminish the CH_4 production that is very sensitive to temperature (Hansen et al., 2006). Indeed, Husted (1994) found that emissions of CH_4 from dung heaps can be divided by factor from 2.7 to 10.3 when heap temperatures were decreased by 10°C.

Increasing the amount of substrate also impacts emissions with typically reduction in NH_3 and N_2O productions but variable effects on CH_4 production (Yamulki et al., 2006; Rigolot et al., 2010; Philippe et al., preliminary results). The addition of litter materials increases the C/N ratio and the aeration of the manure, which favour the bacterial growth and the N assimilation into stable microbial protein resulting in lower NH_3 and N_2O emissions (Dewes, 1996; Sommer and Moller, 2000). Regarding CH_4, substrate supply may inhibit production because of greater aeration on one hand, but may promote emissions by providing degradable carbohydrates for methanogenic bacteria on the other hand (Yamulki, 2006).

Some research addressed the effect of the surface of the bedded area on emissions. Contradictory results were obtained whatever the gas studied, NH_3, N_2O or CH_4 (Hassouna et al., 2005; Rigolot et al., 2010; Philippe et al., 2010b and in press). This indicates that emissions from litter greatly depends of particular conditions inside the manure (C/N ratio, aeration, temperature) rather than just space allowance

With deep litter systems, NH_3-, N_2O- and CH_4-emissions increase regularly in the course of time, principally thanks to accumulation of dejection and compaction (Philippe et al., 2007a, 2010b, 2012b). Therefore, like for slurry systems, frequent manure removal was proposed to reduce these pollutant emissions. In this way, straw flow systems have been developed combining regular straw supply, sloped floor and frequent manure scraping (Bruce, 1990). This kind of manure management is efficient to reduce N_2O and CH_4 emissions but increases NH_3 emissions (Amon et al., 2007, Philippe et al., 2007b; Philippe et al., 2012b). While the aeration of the manure during the scraping and removal inhibits the production of N_2O and CH_4, this technique fails to reduce NH_3 emissions because spreading of faeces and urine over the floor enhances NH_3 synthesis in place of promoting microbial N assimilation. As it is for the slurry, reduction of total emissions can be achieved provided lower outside temperature during storage than inside or specific manure treatments.

Several pen designs were elaborated to stimulate the separation of the excretory and lying behaviours, and thus to limit pollutant emissions. Some strategies associate bedded floor with slatted floor and/or solid floor. Jeppsson (1998) tested fattening pen composed of a bedded area at the front of the pen for feeding and resting (0.90 m²/pig) and a slatted floor area at the back of the pen for dunging (0.25 m²/pig). With straw-based litters, emissions were around 20-25 g NH_3/pig.day. These quite high emissions were partly explained by the clogging of the slatted floor with bedding material. A pen design with a sloped concrete floor as feeding and lying area (0.84 m²/pig), and a deep litter as excreting area (0.54 m²/pig) resulted in lower emissions, with on average 8.3 g NH_3/pig.day (Kaiser and Van den Weghe; 1997). A model was developed by Groenestein et al. (2007) to predict the NH_3 emissions from a litter system for group-housed sows combining straw bedded area, concrete floor and slatted floor. The model showed that increased urination frequency in the straw bedding rather than on the other floor types lowered the emissions. Therefore, pen designing should be aimed at decreasing excretory behaviour on solid and slatted floors and allowing more excretion on litter.

Conclusions

Several mitigation techniques are available to reduce NH_3-, N_2O- and CH_4-emissions from pig houses, whatever the floor type. However, some strategies show contradictory effects depending on the circumstances and the gas. By example with slatted systems, reducing the emitting surface by implementing a partly slatted floor is efficient to decrease the emissions on condition that attention is paid to prevent the soiling of the solid part of the floor. With bedded systems, the use of sawdust in place of straw reduces the emissions of NH_3 and CH_4 but increases the emissions of N_2O. Anyway, solid manures produce significantly more N_2O than slurry, which constitutes the main inconvenient of bedded systems. Since pollutant emissions also occur during storage, treatment and spreading of manure, complete evaluation of the entire manure management process is needed to really limit global emissions. Some options should prevent potential reduction in a next step or constitute opportunities to further diminish the emissions. In addition, the choice for a housing system is also guided by other factors, such as animal health, performance and welfare, agronomical values of manure and surely the investment and operating costs. Specific field conditions will guide decision in favour of mitigation techniques.

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10. Ammonia volatilization from manure during storage and after application in the field

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Ammonia (NH_3) may be emitted from the animal houses, solid manure or liquid manure stores, compost heaps and manure applied to fields (Sommer et al. 2003, 2006). This emission is worldwide the most significant source of NH_3 to the atmosphere.

Ammonia is a reactive gas that combines readily with NO_3^- and SO_4^{2-} to form particulates, which is a risk to human health (Renard et al. 2004). In addition, deposited NH_3 and wet and dry-deposited particulate ammonium may cause acidification and eutrophication of natural ecosystems (Brandt et al. 2011; Sutton et al. 2011). Ammonia also contributes to anthropogenic greenhouse gas emissions, being a significant source of indirect N_2O emissions that result from land deposition and is thus included in the GHG emission inventories (IPCC 2006).

Ammonia volatilization from agricultural sources represents a significant loss of N which would potentially have been available for crop growth. Ammonia emission ranges from 3 to >50% of total ammoniacal nitrogen in manure ($TAN=NH_3+NH_4^+$; Sommer et al. 2003, 2004). This variation reduces the predictability of the mineral fertilizer efficiency (MFE) or N-fertilizer replacement value (NFRV) of manures, and will inevitably encourage the application of surplus N relative to plants requirement in order to ensure a sustainable harvest.

Robust quantification of NH_3 emissions from agricultural sources is important both for producing accurate inventories required to show compliance with international legislation and for contributing to develop mitigation methods to reduce emission and improve the efficiency of N use within agriculture.

The intention with this chapter is to present some concepts for calculations of NH_3 emission from stored manure that take storage geometry, climate, TAN concentration and pH of slurry into account. Using this concept instead of simple conservative emission factor may give a better estimate of the emission. In addition is for stored and applied manure presented standard emission factors that can be used when estimating gross NH_3 emission from a larger region.

Solid manure heaps

Solid manure may be stored and composted in heaps that are open to the surroundings or in heaps that may be covered with plastic not being air tight and with openings between the manure and atmosphere or heaps that are tightly covered by e.g. plastic sheets or clay and the like.

Covering the heaps tightly will most probably stop air from being exchanged between the heap and surrounding air and NH_3 emission from heaps may be assumed to be negligible as will CH_4 and N_2O emission, similar to the heaps covered with PVC in the study of Hansen et al. (2006). If the heaps are uncovered or not closed completely or compacted to reduce air transfer and composting starts then NH_3 emission may be related to the temperature of the heap (Fig. 1). Because little information is available about temperature of heaps in relation to covering, compaction etc. then in future one may consider to relate the emission factor to heap covering, which have a strong influence on the microbial transformation of the organic matter that affect temperature, which is most important for NH_3 emission.

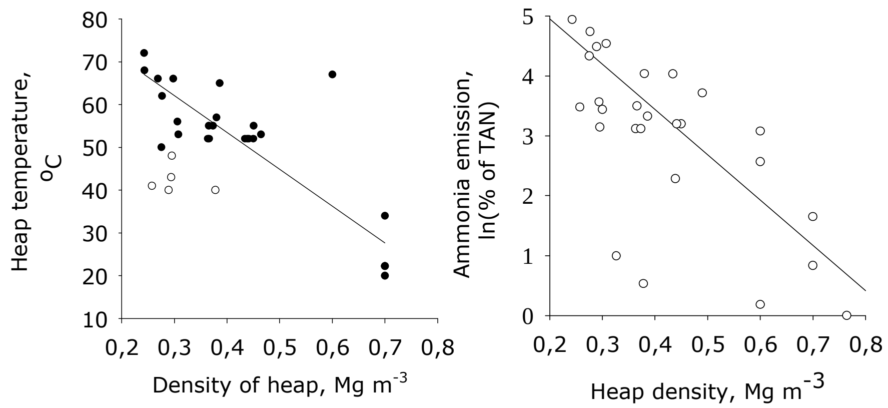

***Figure 1**. Left: Temperatures in livestock manure heaps related to manure density the open symbols are data from experiments where the heaps were covered with PVC sheets or surrounded by walls. Right: Ammonia emission from livestock manure heaps related to manure density (From Web et al 2012).*

Emission factors are varying from being negligible to being very high (Table 1), and may account for more than the initial TAN (NH_3+NH_4^+) in the manure, because NH_3 lost origin from mineralised organic N (Webb et al. 2012). This variation in NH_3 emission is due to the effect of treatment of the manure i.e. storage time, aeration and temperature, factors that often is not described well in the articles presenting the NH_3 emission data. The effect of temperature is significant and is related to porosity, air permeability and water content (Poulsen and Moldrup 2007), because temperature is related to aerobic microbial activity (Sommer et al. 2004). In consequence the NH_3 emission factors could be calculated using the following algorithms (Webb et al. 2012):

$F_1(D)=6.5-7.6*D$, $r^2=0.498$ (Eq. 1)
$F_2(D)= 3.5 – 2.6*D$, $r^2=0,28$ (Eq. 2)

$F_1(D)$ is an ammonia emission factor given as ln(% of TAN) and $F_2(D)$ as ln(% of N-total) in manure and D is heap density, Mg m^{-3}. The algorithm reflects that NH_3 emission declines exponentially at reduction of heap temperature and this temperature declines with increasing heap density.

If there is no knowledge about the standard management of manure by farmers on a farm, in a region or in the country, then one may use the average emission factors given in table 1.

__Table 1__. Average ammonia emission factors from solid manure heaps collected by Web et al. (2012) in a European project.

		% of total N			
		Ave	**SD**	**Max**	**Min**
Cattle (24*)	FYM **	15.1	13.9	44.8	0.1
Cattle (13)	Deep litter	7.8	9.2	23.0	-
Cattle (4)	FYM tied stall	3.7	3.2	8.0	0.6
Pig (13)	FYM	30.8	37.8	123.4	0.1
Pig (4)	Deep litter	4.8	2.1	7.0	2.4
Poultry (4)	Removed daily with conveyer belt	2.1	1.8	4.5	0.0
Poultry (13)	Litter	8.3	5.9	18.4	0.3

*The figures in brackets refer to the number of studies from which the values were derived.
**Farm yard manure collected by scraping excreta mixed with urine from the floor of the animal house

Ammonia emission from liquid manure stores

Emission of NH_3 from a surface is driven by the concentration gradient between the NH_3 in the air immediately adjacent to the surface (NH_3(g)) and that in the ambient atmosphere ($NH_{3,a}$). The height of this boundary layer varies according to meteorological conditions and surface roughness. The flux of NH_3 (F_A; mol m^{-2} s^{-1}) is obtained from the following equation:

$$F_A = K(u) \cdot A \cdot ([NH_3(g)] - [NH_{3,a}(g)]) \qquad \text{(Eq 3)}$$

where K(u) is a transport coefficient (m s^{-1}), which is affected by diffusion and convection in air and is mainly dependent on wind speed, surface roughness and temperature, A is the surface area of the lagoon and NH_3(g)) is the equilibrium concentration of the NH_3 concentration in the air immediately over the gas – liquid interphase (mol L^{-1} or g N L^{-1}). ($NH_{3,a}$(g)) is the ambient concentration of NH_3, which traditionally is considered insignificant in relation to (NH_3(g)) and is not included in the calculations.

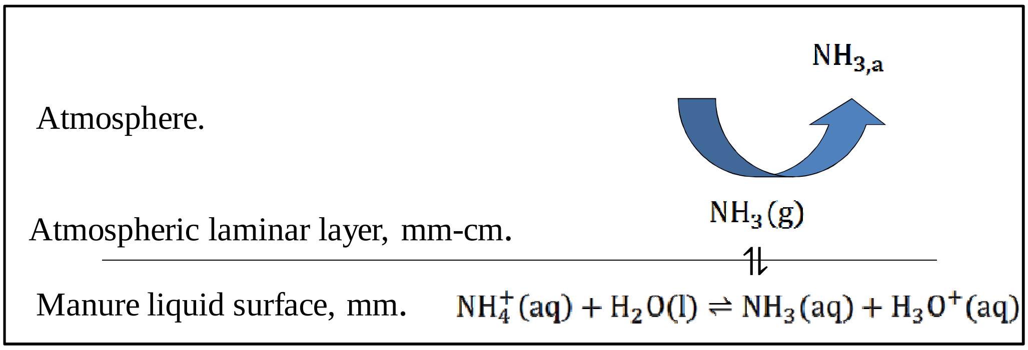

Figure 2. *Release of NH_3 from a liquid solution of TAN (NH_3+NH_4^+) to the atmosphere.*

The concentration of gaseous components $NH_3(g)$ in the air just above the liquid surface is proportional to the activity of the component in the solution. The relationship between the different ammoniacal species in the liquid and gas phases is as follows:

$$NH_4^+(aq) + H_2O(l) \rightleftharpoons NH_3(aq) + H_3O^+(aq) \qquad \text{(Eq 4)}$$
$$NH_3(g) \rightleftharpoons NH_3(aq) \qquad \text{(Eq 5)}$$

From these equilibria, which are effectively obtained instantaneously, The atmospheric NH_3 concentration $NH_3(g)$ in equilibrium with the concentration of TAN ($[TAN] = [NH_4^+] + [NH_3]$) at the surface of the slurry can be calculated by the equation:

$$[NH_3(g)] = \frac{1}{K_{H,NH3}} \cdot \frac{[TAN]}{1 + [H^+]/K_N} \qquad \text{(Eq 6)}$$

where K_N is the dimensionless equilibrium constant for NH_4^+/NH_3 (Table 2), and concentrations are given in mol L^{-1}, and $K_{H,NH3}$ is the Henry's constant (molal atm^{-1}).

In the Danish ammonia emission inventory it is assessed that over the year 11.4% of TAN in pig slurry transferred to the stores are emitted to the air (Hansen et al. 2008). One may estimate the transfer coefficient to be 0,0072 m s^{-1+}, if it is assumed that during one year the slurry stores are gradually being filled to a depth of 4 m, average TAN concentration are 2.8 g N L^{-1} and pH 7.5 (Sommer and Husted 1995) and then calculate a monthly emission using normal air temperature (DMI 2012). Air and stored slurry temperature are near similar in Denmark (Hansen et al. 2006).

***Table 2**. Equilibrium constants used to calculate NH_3 emission from a liquid manure store. Temperature (T) is in degrees Kelvin (273.15 + x ^oC). Beutier & Renon, 1978.*

Reaction	**K_H (molal atm^{-1}), K_{NN} or K_{H2O} (no dimensions)**	K_H and pK at 25^{o}C
$NH_3(g) \rightleftharpoons NH_3(aq)$	$\ln(K_{H,NH3}) =$ $-(160.5 - 8621/T - 25.67 \cdot \ln(T) + 0.0353 \cdot T)$	60.38
$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$	$\ln(K_{NH3}) =$ $191.9 - 8451/T - 31.43 \cdot \ln(T) + 0.0152 \cdot T$	4.75
$H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq)$	$\ln(K_{H2O}) =$ $14.01 - 10294/T + 0 \cdot \ln(T) - 0.0392 \cdot T$	13.99
$NH_4^+(aq) \rightleftharpoons NH_3(aq) + H^+(aq)+$	$n(K_{NH4}) = \ln(K_{H2O}) - \ln(K_{NH3})$	9.24

In this calculation the transfer coefficient is assumed to be constant over the year, which is not correct but information for improving the calculation is missing. The transfer coefficient K_c (m s^{-1}) for NH_3 transfer from a source of NH_3 to the air can be calculated with the following simple model, as a function of temperature (^{o}C), wind speed (u, m s^{-1}) and the length (l, m) of the emitting surface (Montes *et al*., 2009):

$$K_{C1} = 0.000612 \cdot u^{0.8} \cdot T^{0.382} \cdot l^{-0.2} \qquad \text{(Eq 7)}$$

Using average monthly air temperature and an average wind speed of 4 m s^{-1} and assuming the average length of the storage is 10 m then an emission of NH_3 over the year can be calculated (Figure 3)

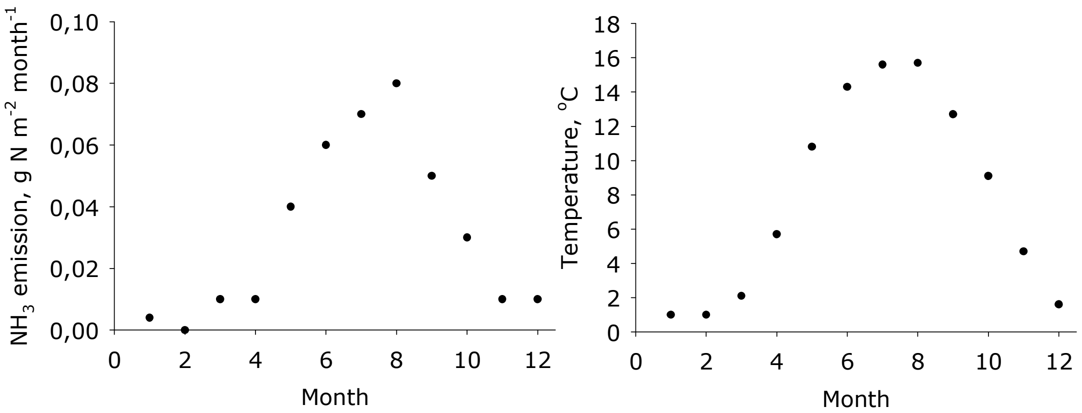

Figure 3. *Left: Monthly average ammonia emission from a Danish liquid pig manure store (pH is 7.5; TAN 0.2 g L^{-}) affected by monthly air temperature shown to the right and at an average wind speed of 4 ms^{-1}*

The annual emission of NH_3 is then assessed to be 0.36 kg NH_3-N m^{-2} and assuming that the annually flow of slurry during the store is 4 m^3 per m^2 of storage capacity then the NH_3 emission factor will be 4% of TAN flowing through the store, which is much less than the Danish emission factor used in the scenario calculations. Adjusting pH to 7.8, which is a pH often found would give an emission factor of 10%, which is not significant different from the emission factor used in the Danish emission inventory.

The emission from stored liquid manure can be reduced by increasing the transport resistance from the source surface to the atmosphere. Thus covers in the form of roofs of PVC, wood and the like create an impermeable lid over the storage and reduce emissions.

Porous floating surface material has also been shown to reduce NH_3 emissions because it creates a stagnant air layer above the slurry through which NH_3 has to be transported by the slow process of diffusion. This material may be porous textiles, natural surface crust formed by solids floating on the surface, a cover of straw, peat or floating expanded clay particles. Such covers reduce NH_3 emissions by a factor of 0.2-0.99. The lowest reductions occur when the control is covered by natural crust, air temperature is low or the cover on treated slurry has submerged. At low air temperatures NH_3 emissions from stored uncovered slurry are low and emissions from covered storage are therefore not much lower than those from the control.

The cheapest method is to take advantage of the natural crust formation on slurry, which is influenced by both the total content and the nature of the slurry solids. Crusting is unlikely to occur on stores with slurry DM content of <1% and cattle slurries may crust more readily than pig slurries. Slurry crust formation is enhanced by gasification, *i.e*. the release of gases that in the slurry may be transported in bubbles that adhere to the particle fibres and make them float to the store surface. During winter periods with little anaerobic activity and little ebullition, the crust layer may sink and leave the slurry uncovered. This may not be a major problem, because NH_3 emissions are low from uncovered slurry during cold seasons. A cover of straw will provide carbon for the production of VFA, which will contribute to a reduction in pH in the surface of the slurry and thereby reduce NH_3 volatilisation. Oil covers have been shown to reduce emissions in pilot studies where 3 mm of oil had little effect and 6 mm was very efficient. However, in practice this treatment has not proven useful, partly because the oil can be transformed by microorganisms, dissolved in the liquid or by crusting, or removed from part of the slurry surface by wind.

Clay granules and straw covers may also reduce odour emissions and the porous textile membranes have been developed for both reducing NH_3 emissions by reducing transport and reduce odour emissions through oxidation of the odour components by microorganisms harboured in the oxic environment of the membrane. However, the odour reduction may not always be reduced by the textile membranes.

In addition to reducing the NH_3 emissions, slurry covers also reduce CO_2 emissions. Consequently, both the TAN and the TIC concentrations are higher in stored slurry with a cover than in uncovered slurry. The reduced emissions of pH buffers may cause bulk pH to be lower in covered slurry. However, the cover may also reduce oxidation of organic acids and the insulating effect of covers may increase slurry temperature and thus enhance organic acid production, which is increased by having a straw cover on slurry. Straw and crust have been shown to reduce CH_4 and increase N_2O emissions from stored manure in Danish studies but straw did not affect CH_4 emissions in an Italian study. A porous textile membrane reduced N_2O emissions but not CH_4 emissions because the latter was continually delivered to the surface through ebullition.

Ammonia emission from manure applied in the field

High rates of NH_3 volatilization has been measured immediately after slurry application due to both the initially high NH_4^+ concentration in the soil surface and the rise in pH in the soil surface. The pH in the soil slurry mixture increases because CO_2 volatilizes faster than NH_3 and because of the degradation of volatile fatty acids (VFA). The cumulative NH_3 loss increases hyperbolically with time (Søgaard et al., 2002). Generally, the rate of NH_3 volatilization from applied manure is very low after a few days, because the concentration of dissolved NH_4^+ in the soil surface decreases rapidly due to volatilization and infiltration. Usually 50% of the total NH_3 loss occurs within 4 to 12 h after slurry application (Pain et al., 1989; Moal et al., 1995). Total emission of ammonia may account for up to *ca.* 42% of the TAN applied in manure (Table 3). The rate of NH_3 volatilization from slurry applied to soil is related to temperature and solar radiation (Sommer et al. 2003); the higher the temperature the larger and faster the NH_3 loss. At low temperature and on frozen soil, volatilization may continue for a long time and result in a large cumulative NH_3 loss. In this case, the large losses are explained by low rates of infiltration of NH_4^+ in the soil (Sommer et al., 2003). Incorporating slurry into the soil is a very effective way of decreasing NH_3 volatilization. Incorporation of slurry by ploughing or by rotary harrow immediately after surface application of slurry decreases NH_3 losses by 50% (Table 3)

Table 3. *Ammonia volatilization from surface broadcast slurry, from slurry injected into the soil and slurry that has been applied onto the soil and incorporated. Effect of incorporation varies according to time lag between application and incorporation (Hansen et al. 2008).*

Season	**Soil surface and Crop**	**Application technique**	**NH_3-loss, % of applied TAN**	
			Pig	Cattle
Spring	Bare soil	Trailhose	17,1	32,6
		Trailhose and incorporation*	5,0	9,4
		Injection 3-5 cm bare soil	1,7	3,3
	Cereals	Trail hose	14,8	28,1
	Grass	Trailhose	17,1	32,6
		Injection 3-5 cm bare soil	12,8	24,5
Summer	Bare soil	Trailhose	22,4	42,7
		Trailhose and incorporation*	6,5	12,4
		Injection 3-5 cm bare soil	2,2	4,3
	Grass	Trailhose	22,3	42,5
		Injection 3-5 cm	16,7	31,9
Autumn	Grass	Trailhose	21,8	41,6
		Injection 3-5 cm	16,4	31,2

**Incorporation by plough or rotary harrow six hours after application of manure on soil.*

Shallow direct injection of slurry (3-5 cm) can decrease losses by up to 70%, while deep injection (35cm) will stop losses almost completely. Furthermore, application of slurry with trailing hoses on the soil beneath a crop canopy may decrease NH_3 volatilization by more than 50%; the efficiency of this technique increases with increasing leaf area and height of crop (Thorman et al., 2008).

Table 4. *Ammonia emission from cattle and pig solid manure or farm yard manure (FYM) applied in the field. The applied manure is left on the surface or incoporated into the soil after 6 , 4 or 1 hour. Incorporation is either by plowing or harrowing (Hansen et al. 2008).*

Incorporation method	**Season**	**Incorporation lag time after application**			
		None	**6 hours**	**4 hours**	**1 hour**
		NH_3-N emission, % of NH_4^+ -N			
Ploughing	Spring	65	39	22	13
Ploughing	Summer	80	48	32	16
Ploughing	Autumn	55	33	12	11
Ploughing	Winter	45	27	7	9
Harrowing	Spring	65	41	36	27
Harrowing	Summer	80	54	48	35
Harrowing	Autumn	55	30	27	21
Harrowing	Winter	45	22	20	17

Losses of NH_3 from solid animal manure applied to soil are not as well understood as the emission from applied slurry, and there are fewer estimates of emission rates as indicated by Table 4. The pattern of NH_3 volatilization over time from solid manure is different from that of slurry. The initial rate of loss from solid manure is low, but volatilization continues for a long period, probably because

the NH_4^+ from the solid manure infiltrate into the soil more slowly than NH_4^+ from slurry (Chambers et al., 1997). The few studies on NH_3 emission from solid manure applied to soil indicate that about 50% of the loss occurs within 24 h of application and that volatilization may continue for about 10 days (Web et al. 2012). Ploughing of solid manure into the soil decreases NH_3 losses (Table 4).
To my knowledge there are no measurements of NH_3 emission from beef feedlot manure applied on the land, therefore the emission rate of NH_3 from cattle FYM is used as an estimate of the emission from applied beef lot manure.

Conclusions

A concept for calculating NH_3 emission from stored liquid and solid manure are proposed. The idea is to better account for temperature, nitrogen and pH effects on the emission and also the method for storing the manure. Further, it is shown that covering manure reduce emission during storage, and incorporating field applied manure into the soil also efficiently reduce emission. Ammonia emission rates from slurry applied with trailhoses is related to crop height, i.e. NH_3 emission from trail hose applied slurry is lower from a field with a high than from a field with a low crop.

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11. Reduction of ammonia emission from poultry houses by nutritional tools

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Introduction

Ammonia is not produced by poultry itself but the volatile nitrogen compound is formed by microbial activity from uric acid and undigested protein in the excreta. This process is affected by moisture content, temperature, acidity, and oxygen concentration in the excreta. It's therefore possible to influence the formation of ammonia by nutritional means. Many publications are available on the effect of nutritional means on the reduction of nitrogen excretion in laying hens en broilers.

Phase feeding

Phase feeding is an instrument to match protein and amino acid supply with the requirement of the birds at different age intervals. A more accurate application of phase feeding at different ages may result in a higher reduction of ammonia emission. In a broiler study, ammonia emission was reduced by 22% when a 6-phase feeding programme was compared with a 4-phase feeding programme. A more sophisticated phase feeding programme doesn't implicate an increase in feed costs.

Crude protein and free amino acids

Reducing the crude protein content along with extra supply of free amino acids is a feasible tool which can be used in feed formulation. It's important that the ideal amino acid pattern will be met for each poultry species. Ammonia reductions up to 50% were reported when crude protein contents of the diets were decreased. Decreasing the crude protein content will increase the feed costs because free amino acids have to be included in the diet formulation to meet the bird's amino acid requirements. An example on the calculation of feed costs showed that a decrease of the crude protein content in laying hen diets of 30 g/kg at a constant digestible lysine content will result in an increase of feed costs of 16%. A decrease of 5, 10 and 15 g/kg crude protein content in broiler diets resulted in an increase in feed costs of 5, 12 and 19%, respectively.

Dietary electrolyte balance

Lowering of the dietary electrolyte balance (sodium and potassium) may result in a reduced moisture excretion which may result in a lower ammonia emission. The effect of moisture content and structure of the manure on ammonia emission is not clear and was not reported. Additional research is recommended in this field. An example of feed cost calculation showed an increase in feed costs of 3 and 7% when potassium content in broiler diets was decreased with 0.5 and 1.0 g/kg, respectively.

Also the calcium and phosphorus content, calcium-phosphorus ratio and the source of calcium in the diet may influence the moisture excretion. A (partial) substitution of $CaCO_3$ by $CaSO_4$ or $CaCl_2$

may result in a reduction of ammonia emission. Some studies reported in laying hens seemed to be promising, however more research is recommended.

Fermentable carbohydrates

A higher inclusion level of fermentable carbohydrates may result in a lower pH in the excreta by a higher production of volatile fatty acids in the hindgut. However, a high inclusion level of fermentable carbohydrates in the diet may result in increased moisture excretion. In laying hens this measure resulted (along with a lower crude protein content) in a 40% lower ammonia emission. An example on the calculation of feed costs in laying hens demonstrated that an increase of 18 and 38 g NSPs per kg in the diet resulted in an increase of feed costs of 1 and 3%, respectively. In broiler diets, however an increase of 9 and 19 g NSPs per kg resulted in 6 and 13% higher feed costs, respectively.

Feed additives

A lot of commercial feed additives are available which improve nitrogen digestion and utilization or having a urease inhibiting effect or having an ammonia binding effect.

New housing and management conditions

New developments in housing and management conditions of poultry now and in the near future (will) have a major impact on protein and amino acid requirement of all poultry species. It is recommended to start refined research to determine the protein and amino acid requirements of all commercial poultry species and to study the effect on nitrogen excretion and ammonia emission. Only a few publications are available for broiler breeders, turkeys and ducks and additional research is also recommended to refine protein and amino acid requirements and to study effects on nitrogen excretion and ammonia emission in these species. It's important that besides measurements on nitrogen excretion also ammonia emission is determined because ammonia emission is not a linear function of nitrogen excretion.

Conclusions

Reduction of ammonia emission from poultry houses by nutrition is feasible without adversely affecting performance, health and welfare of poultry. However, most nutritional adjustments will result in higher feed costs. Less drastic nutritional adjustments which have less cost price increasing effects, in combination with housing and management adjustments, may result in a significant reduced ammonia emission. Control of feed adjustments may be guaranteed by delivery of low-emission diets with a unique feed label and an accurate described feed composition.

12. A guide on good environmental practices for breeding

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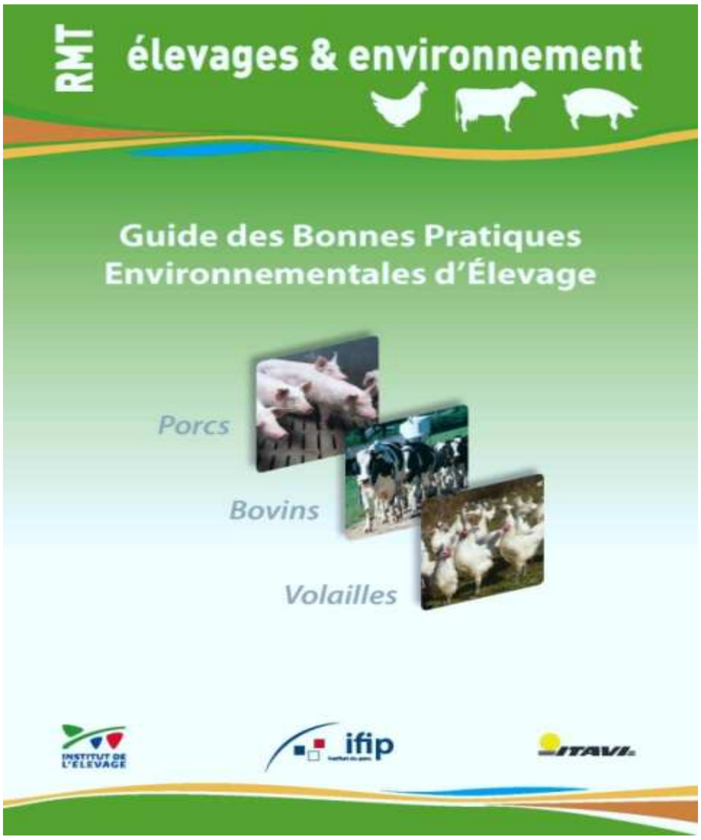
Environmental issues have more and more impacts on national agricultural orientations and have substantially changed during the last ten years. The evolution of regulations has been different regarding the list of environmental parameters linked to animal production. Choosing the right technique in relation with environmental, regulatory but also economic constraints is a real challenge for farmers.



In December 2007, the Technical Network "Breeding and Environment" has been approved by the French government in order to propose and to transfer tools for the improvement of environmental balances in the control of animal production systems. This guide on good environmental practices is one of those tools proposed by the Technical Network .This document is aimed for all those involved in animal production (beef, poultry and pig production) and also provides an over-view of the technical knowledge currently available on how to reduce one or more environmental issues dues to animal production.

But what is a Good Environmental Practice for Breeding (GEPB)? In our guide, a Good Environmental Practice for Breeding is a technique, equipment and/or a management permitting to reduce the environmental impact on water, air and soil. These techniques are very close to the Best

Available Technique (BAT) proposed par the IE Directive but are specific to the French national context. The principles are the same: reduction of the environmental impact of animal production with viable techniques for farms.

The GEPBs listed in this guide met by a list of criteria considered reliable by the authors:

- **Technical reliability of the implementation of the practice**: this point is an essential one. In the close future, the rate of new building is expected to be very low in the coming years. So, it appears essential for GEPB to be easily implemented on already existing buildings. For new buildings, the requirements of feasibility should be less important because it should be integrated in the conception of the units.
- **Technical maintenance**: for equipments, the time spent for the care and the maintenance should be as low as possible.
- **Technical efficiency per environmental parameter**: data published on the efficiency of the GEPB are listed and analyzed.
- **Cross effects**: some techniques should have a positive influence on some environmental parameters but also a negative effect on others. Cross effects must be identified and listed when it is possible.
- **Investment and operating costs**: overall costs must be kept as low as possible for limiting the impact on animal production cost. Those costs should be proportional to the reduction of the impact of the considered environmental parameter.

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For the sake of clarity and in order to facilitate its uses by readers, the GPEBs are presented in the form of data sheets. Therefore, 65 technical data sheets have been written for the three animal productions: beef, poultry and pig productions. In order to make it easy readable and to make data easily available, the structure of each technical sheet is the same and organized under the following headings: principle and description of the technique, implementation, environmental benefits, cross effects, investment and operating costs, and specific regulation. A last heading is dedicated to the literature available on this technique.

In the guide, the GPEB is identified by species but it is noticed if some are common to pig and poultry for example. It is also notified when a GPEB is a BAT in regard to the IE Directive and the IRPP BREF (in its last version – 2003).

This document was conceived and elaborated by the three technical institutes dedicated to animal production (Institut de l'Elevage for beef production, ITAVI for poultry production and IFIP for pig production) as a part of the mission of the Technical Network "'Breeding and Environment". The present version was edited in september 2010 and an update version is expected before the end of 2013. This document is available in bound version upon request from IFIP, Institut de l'Elevage or ITAVI. A free electronic version is also available for downloading from the website of the Technical Network (www.rmtelevagesenvironnement.org).