Review of ammonia emission and deposition research and state of knowledge in relation to the models and factors used in policies

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April 2013 a review team was established on the request of the Secretary of State Dijksma by WUR and RIVM. The task of the team was to review Dutch research on ammonia emissions and deposition and investigated the current state of knowledge in relation to the models and factors used to support and develop policies. The team consisted of Arjan Hensen (ECN), Jan Duyzer (TNO), Egbert Lantinga (WUR) and Jan Willem Erisman (Louis Bolk Institute/VU).

The aim of the review was formulated by the Secretary of State as to review:

- *The international scientific underpinning of the ammonia emission factors for the application of manure;*
- *The international scientific underpinning of the deposition models, such as those used in the 'programmatische aanpak stikstof (PAS)' for the Natura 2000 policies;*
- *The gaps in knowledge that currently exist.*

The international peer review will be based on the Dutch review and on a meeting to be held with international experts. The results of the review will also indicate the possible need for further research on the issues.
The reviewers were asked to answer the following questions: (to be translated)

- Are the emission factors for application of manure as used in the Netherlands scientifically sound? The ministry asked to include the results of the international discussions (related to the paper of Sintermann et al., 2012) about quantification of ammonia emissions from broadcast slurry.
- Is the scientific underpinning for the differences in ammonia emission between broadcast application and other application techniques, such as sod injection, deep injection, and trailing shoe, sufficient to use different ammonia emission factors for these techniques?
- What are the gaps in knowledge in the scientific underpinning of ammonia emission factors, which demands for field measurements of ammonia emission?
- Is the scientific underpinning of the Dutch modelling of the dispersion and deposition of ammonia sufficient and scientific sound?

More specific the review team were asked the following questions formulated by the ministry of Economic affairs, which were taken as an outline for the major conclusions:

- Ammonia-emission factors
  - Are the emission factors (EF) for application of manure as used in the Netherlands scientifically sound?
  - Is the scientific underpinning for the differences between surface application and compared to other techniques such as "sleepvoet, sleufkouter, zodebemesting en diepe injectie " shallow or deep injection, …. sufficient to merit conclusions about the effectiviness in terms of ammonia reduction?
  - What are the gaps in knowledge and the research needs for determining the scientific underpinning of the obligation to apply techniques that incorporate manure into soil ?

- Ammonia deposition modelling
  - Is the scientific underpinning of the Dutch modelling of the dispersion and deposition of ammonia sufficient and scientific sound?

WUR and RIVM provided two cover notes (see attachment), one on the emissions and the other on deposition modelling. A set of background papers and reports were provided along with these notes as scientific background on the research used to support the emission and deposition methods and models. In view of the upcoming international evaluation of the Dutch review, the selection mostly comprised material in English. The review team based their conclusions on this material, some ad hoc literature search, their own knowledge and discussions with WUR and RIVM staff. This report describes the major outcome in two parts: a summary of the major conclusions of the review team and a more extensive report with the findings per question that was requested to address. Each reviewer provided written input for discussion and as background material on emissions and depositions. This material was only meant for internal communication and is not published.

Summary of the review

Within the EU territory the Dutch area is still the hotspot on the map for almost all nitrogen compounds. Much research has been done in the Netherlands on measures to reduce emissions and atmospheric deposition of nitrogen. Measures have been successfully applied and lead to reductions. In view of the costs and burden of emission reduction measures the agricultural sector in the Netherlands asks for more certainty in the emission factors and deposition models used. Much of the research has been done more than ten years ago.

In this review we have focused on the scientific underpinning and how the science is used in policy support. The review is not addressing the choices that have been made on how the knowledge is used in different policies to reduce deposition and emissions. We answered the questions that had to be addressed in this review:

Are the emission factors (EF) for application of manure as used in the Netherlands scientifically sound?

- We conclude that on the national scale the emission factors are based on many experiments under different conditions and therefore may be considered to yield a representative average on this scale. However, the experimental EF's show a large range which is not understood. This is not satisfactory and they should be based upon more than just %TAN lost to increase understanding and make them useful for extrapolation. Moreover all EF are based on experiments carried out more then 10 years ago. These should be repeated to check for systematic changes;
- The mass balance method has been used for nearly all EF. In view of recent discussions and scientific developments the method should be evaluated for systematic biases using other measurement techniques and quantifying the complete N-balance;
- The EF's in international perspective are at the high-end for broadcast spreading and in the same range for other application techniques. Systematic differences are observed between the EF's, probably because of the differences in manure composition and climate;
- The scatter of EF's is too large and not well explained. This makes use on a local or regional scale rather uncertain. More explaining variables should be taken into account such as manure management, composition, soil conditions, climate, etc. This could reduce scatter and at the same time allow more reliable usage of these factors in future applications.

Is the scientific underpinning for the differences between surface application and compared to other techniques such as "sleepvoet, sleufkouter, zodebemesting en diepe injectie " shallow or deep injection, …. sufficient to merit conclusions about the effectiveness in terms of ammonia reduction?

- There is international scientific agreement that incorporation of manure reduces ammonia emissions compared to broadcast spreading. There is however a large range in the EF's for different application techniques;

- On the national scale the effectiveness of some of the application techniques for incorporation of manure is smaller than derived from field trials and in comparison to the international literature;
- The NL field trials might have overestimated effectiveness either due to potential systematic bias in the mass balance method and/or the difference in practical application. The ammonia gap research and the comparison to internationally used quantification of the effectiveness confirms the overestimation;
- The ALFAM database with emission measurements and governing factors should be extended with more recent data to allow trend evaluation and subsequent actualization of emission factors;
- The evaluation of emission models (cascade) is done indirectly through atmospheric observations: more focus on experimental validation is essential.

What are the gaps in knowledge and the research needs for determining the scientific underpinning of the obligation to apply techniques that incorporate manure into soil ?

- A reference measurement technique or well described standard method with known uncertainty for ammonia emission due to application of manure in the field is not yet developed. This is essential to evaluate existing techniques and to further develop mechanistic models to better understand and quantify the governing processes and there with the effect of measures and management to reduce ammonia emissions;
- In addition, dedicated experiments should be designed that can evaluate the hypothetic effects that might affect the current mass balance method estimates. All EF's are justifiably determined using one method. This leads to a fair and transparent situation. In view of comments by Dutch and other European scientists there is a need to evaluate the method for scientific biases through detailed studies and comparisons.
- The manure management, meteorological and climatic effects during the years should be taken into account on the National scale. This can be done by taking into account more factors than %TAN or by doing a set of representative measurements annually;
- Emission models should be based on a more comprehensive description of the emission process, such as the French Volt'air model, especially for the local and regional scale; The current model based upon %TAN is too limited.
- There is a general lack of more recent focused experiments to evaluate the EF's for different abatement techniques under practical conditions. The same holds for farm specific losses of ammonia and other nitrogen components for different management and climate conditions;
- We support the recommendations of the Task Force on Reactive Nitrogen under the UNECE Convention on Long-Range Transport or Air Pollutants:
  - There is a need for a practical assessment of abatement measures to optimize effectiveness
  - Assess the technical feasibility of abatement techniques under regional/specific conditions
  - Investigate emission estimates of solid manures and its abatement technologies
  - Determine the effect of low emission application techniques for mature crops;

– Obtain more statistical information on the spatial variation in manure handling systems and management practices.

Is the scientific underpinning of the Dutch modelling of the dispersion and deposition of ammonia sufficient and scientific sound?

- The available peer reviewed literature on Dutch research on this subject is rather limited, especially if one considers the amount of research carried out. This research could be supported by more peer reviewed publications;
- State of the art modelling is applied on the national scale;.
- Ammonia gap research has provided much insight in the emission – deposition modelling and dry deposition parameterization, leading to good correlations with observations and performing on the national scale; Based on this comparison with observations RIVM concludes that the uncertainty in the estimated ammonia deposition is 30% on the national scale;
- Ammonia gap research provided changes in the dry deposition parameterization for grassland and indications that the effectiveness of manure incorporation techniques should be lowered;
- On the local scale uncertainties in the estimates of the deposition are up to 70%. This is mainly due to the lack of monitoring data to constrain the results and the uncertainty in dry deposition estimates. More measurements in different ecosystems of dry deposition would be needed to improve and test parameterizations;
- More experiments to evaluate the local scale emission – deposition relationships are needed to determine the uncertainty in emissions and in deposition. A more mechanistic description coupling emission and deposition processes is required;
- From a scientific standpoint we recommend to be careful, given the current state of knowledge to go into too detailed policy applications, but this choice is up to the end user.

Main components of the review

Introduction

The discussion on the validity of the NH_3 emission factors for different methods of manure application and the modelling of the deposition is triggered by:

- the large scatter in EF's for individual experiments reported thus far, which suggests that we do not fully understand what is actually happening on a manured field;
- the limitations of agricultural development by the ammonia deposition to nitrogen sensitive natural areas (e.g. Natura 2000);
- the costs made by the agricultural sector to use low emission application techniques.;
- the wish of (groups of) farmers to apply different measures to reduce ammonia emissions, e.g. by water spraying, decreasing TAN content, etc. or to optimize the nutrient cycles at farm level to increase the nutrient use efficiency and thus reduce losses to the environment.

In view of the costs and burden of emission reduction measures the agricultural sector asks for more certainty in the emission factors and deposition models used.

Although the whole setup used thus far to obtain emission data and to calculate concentration and deposition maps over the Dutch territory must be considered state of the art, improvements are still possible. We should keep in mind that within the EU territory the Dutch area is still the hotspot on the map for almost all nitrogen compounds. In every scientific EU meeting discussing nitrogen levels and the impact thereof, the NL label shows up at the high end of N input, concentrations and deposition levels. Being at the end of the spectrum rather than somewhere in the middle, we in the Netherlands have specific issues both in measurements and in calculation that are unlikely to be solved by people abroad. Up to the beginning of this century this situation has lead to much Dutch research on EF as well as on dispersion and deposition of ammonia. The effort is larger than in any other country. However, recent discussions on the methods used in the Netherlands to derive emission factors have shown that there is a need for more research.

As requested we have focused on the scientific underpinning and how the science is used in policy support. The review is not addressing the choices that have been made on how the knowledge is used in different policies to reduce deposition and emissions. Were needed we distinguish two levels: the National and the local scale (for example between 0,5 to 10 km km).

Ammonia emission factors (EFs)

The available data

The Netherlands has one of the most elaborated datasets in this field, which makes sense considering the fact that it has been a European hotspot of nitrogen emissions including those on NH_3. The dataset covers a range of conditions and types of manures applied in the Netherlands on grassland and arable land and is therefore representative for the national scale. The number of measurements differ per application technique, most of the data are available for broadcast spreading and shallow injection.

The current emission factors are all based on one measurement methodology; the so-called mass balance technique. Having all application techniques evaluated by one and the same method is in principle transparent and fair. The potential danger is that if a systematic bias (non random) is in the measurement method or its interpretation, this can have consequences for the application of the results. The large variation in the emission factors reported for a single application technique might be real but does not help to take away this concern.

Sinterman et al. (2011) list a number of hypotheses for different measurement methods used all over Europe that could lead to a systematic bias in the emission factors obtained. Those hypotheses that might change EF levels by more than 5% should be tested for they will show whether or not the national EF's are biased and they might help to reduce the differences between different experiments.

Furthermore, most of the data used in the Netherlands are more than 10 years old and changes in manure management and climate might have had an effect on the EF's, which is not detected. There is a of lack of more recent measurements. The EF's are expressed as fraction TAN lost from the manure. The different experiments show a very large range in EF per year and/or application technique. Despite the fact that the driving forces for the emission other than TAN are known and have been assessed in e.g. the ALFAM database and model, these are not used. The review team considers the use of TAN level data only to calculate emission too limited. This could lead to systematic biases especially when the TAN based model is used in situations where there are no more measurements available. Sintermann et al. (2011) conclude this in their overview paper. They show a trend in EF over the years which suggest lower EF's for recent years compared to those measured 10 years ago. According to our assessment the difference could be explained by taking other factors into account, especially the dilution (as expressed in the dry matter content of the manure).

Other EU countries use the same method to calculate the NH_3 emission based on %TAN lost. The international datasets are, however, less extensive than available in the Netherlands. These data show the same large variation, but in general lower averages for broadcast spreading of manure and also a smaller difference between the different application techniques (de Haan et al., 2009). This might be explained by the different manure composition and or climatic differences, but supports the observation that %TAN as the only factor for estimation the emissions is unsatisfactory.

Q. 1. Are the emission factors (EF) for application of manure as used in the Netherlands scientifically sound?

Major conclusions:

- We conclude that on the national scale the emission factors are based on many experiments under different conditions and therefore may be considered to yield a representative average on this scale. However, the experimental EF's show a large range which is not understood. This is not satisfactory and they should be based upon more than just %TAN lost to increase understanding and make them useful for extrapolation. Moreover all EF are based on experiments carried out more then 10 years ago. These should be repeated to check for systematic changes;
- The mass balance method has been used for nearly all EF. In view of recent discussions and scientific developments the method should be evaluated for systematic biases using other measurement techniques and quantifying the complete N-balance;
- The EF's in international perspective are at the high-end for broadcast spreading and in the same range for other application techniques. Systematic differences are observed between the EF's, probably because of the differences in manure composition and climate;
- The scatter of EF's is too large and not well explained. This makes use on a local or regional scale rather uncertain. More explaining variables should be taken into account such as manure management, composition, soil conditions, climate, etc. This could reduce scatter and at the same time allow more reliable usage of these factors in future applications.

Background

General

- Many experiments have been done and a large dataset over the years has been established with measurements made with the same method (mass balance or IHF); The data provide an acceptable average for the national scale for grassland and arable land for broadcast spreading and shallow injection.
- Most of the experiments and literature that underpin the EFs are more than 10 years old, which introduces the inherent uncertainty that changes in for example manure composition, management practices or climate will not be reflected in annual emission reporting;
- The data are published in Dutch and international reviewed papers and internationally used as a reference and in databases such as ALFAM;
- Regarding the scientific underpinning for the high national emission factor for broadcast spreading it is questionable whether this can be confirmed through the scientific knowledge on uptake and immobilization of N. There is significant uptake of mineral N (TAN) by the growing herbage in all experiments which have been carried out the last decades. Furthermore, we should not forget that also in the order of 30% of the applied slurry TAN can be immobilized in the soil in the year of application (See e.g. Sorensen, P. and E.S. Jensen (1996), Plant and Soil, 183, 213-220). This should be further investigated.

Mass balance method

- As for the mass balance measurement technique used, a few comparison studies (Schagerbrug/Duiven, 1998; STOP; Veld, 2008; Lidar and plume, 2008) have been made in the Netherlands using alternative measurement techniques (static or dynamic plume, enclosures, open boxes, tracer method, etc.). In general the different methods were in the same order of magnitude and showed similar variations in emissions.
- However, also differences were observed. Until now these results have not lead to further research on the potential biases of the mass balance method. It is known for example that a backward turbulence correction is needed, but no measurements are available to make this correction (See Sintermann et al., 2011). The differences shown in a small set of intercomparison measurements were not considered representative enough to change the general used IHF method.
- Sinterman paper (2011) lists limitations for different methods used all over Europe, including the mass balance method, which can be systematic in nature. A careful evaluation of these is essential to determine the uncertainty and potential systematic bias in the mass balance method;
- Intercomparison studies both in 1999 and 2008 concluded that in order to understand the differences in the measuring methods a mechanistic model that describes the emission process is required.

International aspects

- EFs used in models to estimate the National emissions are based on Dutch measurements only and are the averages of data with a very large range.
- International experiments and results have been used to show the ranges in relation to the Dutch EFs. This range is very large and the Dutch EF's for broadcast spreading are at the high end. So far the international comparisons have had no influence on the determination of averages for the Netherlands. This might be explained by differences in manure composition, but this has not been demonstrated;
- Recently these EF's are based on %TAN lost, which is done also in other countries and recommended by the UNECE. However, the range in EF's based on %TAN is very large and the literature (ALFAM, Sintermann, Misselbrook, TFRN, etc.) shows other factors such as pH, temperature, water, Dry Matter, etc. play a major role. Especially Dry Matter is an important factor, which a.o. might explain the annual trend in EF's observed by Sintermann et al (2011). This knowledge should be used to explain the large variation and for generalisation of EF's;
- Taking these parameters into account would possibly allow understanding of the large scatter in measurement results and might reduce the uncertainty in local application of emission factors, which are now the national averages.

Cascade of emission

- This review focuses on manure spreading emissions, but the emission of ammonia takes place in the whole chain and a molecule lost in the housing system cannot again be lost from the field (other than deposition and re-emission). It is a matter of equilibrium. Specific EFs for the different phases of manure management, such as during animal housing, storage and application of manure, and for different housing systems, animals, spreading systems, etc. are currently used. In this way there is a consistent modelling of the cascade of emissions in the manure

production and handling process. The danger of this is that when a systematic bias is introduced in the early part of the cascade this will have an effect on all the calculated losses downstream.
- This calls for a mechanistic modelling of the emission process in the whole cascade instead of using empirical factors.
- All measurements are used as empirical factors and therefore there is no independent dataset available for model validation.

Q. 2. Is the scientific underpinning for the differences between surface application and compared to other techniques such as "sleepvoet, sleufkouter, zodebemesting en diepe injectie " shallow or deep injection, …. sufficient to merit conclusions about the effectiveness in terms of ammonia reduction?

Major conclusions:
- There is international scientific agreement that incorporation of manure reduces ammonia emissions compared to broadcast spreading. There is however a large range in the EF's for different application techniques;
- On the national scale the effectiveness of some of the application techniques for incorporation of manure is smaller than derived from field trials and in comparison to the international literature;
- The NL field trials might have overestimated effectiveness either due to potential systematic bias in the mass balance method and/or the difference in practical application. The ammonia gap research and the comparison to internationally used quantification of the effectiveness confirms the overestimation;
- The ALFAM database with emission measurements and governing factors should be extended with more recent data to allow trend evaluation and subsequent actualization of emission factors;
- The evaluation of emission models (cascade) is done indirectly through atmospheric observations: more focus on experimental validation is essential.

Background
- The total number of EF measurements was 199 on grassland, of which 81 for surface spreading, 29 for narrow band application and 89 for shallow injection. For arable land 58 measurements are available, of which 26 for surface spreading, 25 for surface incorporation and 7 for deep placement. This is a fairly large dataset and well represented for broadcast spreading and shallow injection. The other techniques are less well represented. Furthermore, the measurements mainly date from more than 10 years ago.
- The literature is in agreement that the techniques for reducing ammonia emissions for manure application reduce the ammonia emissions, but also odour and increases nutrient use efficiency (with decreasing N-application rates). However, the effects are highly variable and depend on many factors, both environmentally (soil, weather, etc.), technique and practical application;
- The EFs for surface application in the Netherlands, which are the reference with respect to the other application techniques, are in the high range given the international literature. The high dry matter content of the manure compared to other countries can provide a possible explanation for this. In the Netherlands we limit addition of water to

manure for example to reduce transport cost. Consequence of this is that differences in DM content for different regions in the Netherlands will cause a systematic deviation from the national averaged EF which is not accounted for.

- The scientific analyses that explains these differences and the underlying factors is not used in the national emission models, which are based only on %TAN and might lead to systematic biases if the management practice, manure composition or climate changes over the years;
- The difference between surface spreading and the abatement techniques as derived from field experiments is rather high and higher than reported in the international literature (de Haan et al., 2009). The inclusion of more explaining variables in addition to %TAN might explain the differences. It is also recommended that the ALFAM database with emission measurements and governing factors should be extended to more recent years;
- When the average EF's are used in emission models and the range is not taken into account, the absolute difference resulting from national estimates can only be correct when there is no systematic bias in the measuring method or in the representatively of the measurements for practical implementation. The large differences in EF's between experiments, however, cannot be properly explained. The EF's plotted versus TAN level show a large scatter. When the average EF from a big cloud of data points is used in the emission model, which is common practice all over Europe, is unsatisfactory from a scientific point of view. This is especially problematic when there the "cloud" is populated with a relatively small number of data points as is the case for the emission reduction application techniques.
- On the local or regional scale the averages and the average difference cannot be used because of the large variation in the other explaining variables;
- From other research evaluating the effectiveness of abatement techniques ("ammonia gap research") there have been indications that the effectiveness is overestimated in the models for the national scale. Since the differences are based on measurements the question is if the quality of these measurements is enough and/or if the way the measurements were performed are representative for the practical application in the field. The latter is probably not the case.
- Since all measurements of the EF's for the different techniques are used as empirical factors there is no independent dataset available for model validation. Furthermore, there are almost no field experiments where the whole N-balance is measured (and closed), including all the individual loss terms. This is essential for the evaluation of the models
- The evaluation of emission models (cascade) is done indirectly through atmospheric observations: more focus on experimental validation is essential

Q. 3. What are the gaps in knowledge and the research needs for determining the scientific underpinning of the obligation to apply techniques that incorporate manure into soil?

Major conclusions

- A reference measurement technique or well described standard method with known uncertainty for ammonia emission due to application of manure in the field is not yet developed. This is essential to evaluate existing techniques and to further develop mechanistic models to better understand and quantify the governing processes and there with the effect of measures and management to reduce ammonia emissions;
- In addition, dedicated experiments should be designed that can evaluate the hypothetic effects that might affect the current mass balance method estimates. All EF's are justifiably determined using one method. This leads to a fair and transparent situation. In view of comments by Dutch and other European scientists there is a need to evaluate the method for scientific biases through detailed studies and comparisons.
- The manure management, meteorological and climatic effects during the years should be taken into account on the National scale. This can be done by taking into account more factors than %TAN or by doing a set of representative measurements annually;
- Emission models should be based on a more comprehensive description of the emission process, such as the French Volt'air model, especially for the local and regional scale; The current model based upon %TAN is too limited.
- There is a general lack of more recent focused experiments to evaluate the EF's for different abatement techniques under practical conditions. The same holds for farm specific losses of ammonia and other nitrogen components for different management and climate conditions;
- We support the recommendations of the Task Force on Reactive Nitrogen under the UNECE Convention on Long-Range Transport or Air Pollutants:
  - There is a need for a practical assessment of abatement measures to optimize effectiveness
  - Assess the technical feasibility of abatement techniques under regional/specific conditions
  - Investigate emission estimates of solid manures and its abatement technologies
  - Determine the effect of low emission application techniques for mature crops;
  - Obtain more statistical information on the spatial variation in manure handling systems and management practices.

Background

- A reference measurement technique or standard method with known uncertainty for ammonia emission due to application of manure in the field is not yet developed. This is essential to evaluate existing techniques and to further develop mechanistic models to better understand and quantify the governing processes and there with the effect of measures and management to reduce ammonia emissions;
- There is no evaluation of the potential systematic biases in the mass balance method and assess the effects on the current emission factors and therewith the effect of abatement technologies;
- A database with emission measurements and its drivers is lacking. Such a database could be used to derive an improved parameterization of the emission process. Furthermore, it could be used to evaluate models. The current available ALFAM database should be extended. Both emission measurements and the characteristics and conditions to determine the determining factors that allow better modelling of the emission of NH_3

must be included. The current ALFAM database/modelling system encompasses these data up to 2001.

- There are no Emission models available that can be applied on the regional and local scale using local factors instead of national averages. This requires that EFs are used based on more parameters than TAN.
- Already in 1999 the STOP research team concluded that mechanistic modelling of the NH_3 exchange would be needed to better understand the emission pattern and the differences in EF's between experiments. Only recently the first preliminary results of that kind using the French Volt'air model are becoming available and this work should be elaborated and a combination should be made with new experiments that can validate the model assumptions.
- We support the recommendations of the Task Force on Reactive Nitrogen under the UNECE Convention on Long-Range Transport or Air Pollutants who has formulated several recommendations for manure application and the emission estimates which are relevant for the Netherlands:
  - There is a need for a practical assessment of abatement measures to optimise effectiveness
  - Assess the technical feasibility of abatement techniques under regional/specific conditions
  - Investigate emission estimates of solid manures and its abatement technologies
  - Determine the effect of low emission application techniques for mature crops;
  - Obtain more statistical information on the spatial variation in manure handling systems and management practices.

Ammonia deposition modelling

Q. 4. Is the scientific underpinning of the Dutch modelling of the dispersion and deposition of ammonia sufficient and scientific sound?

Major conclusions

- The available peer reviewed literature on Dutch research on this subject is rather limited, especially if one considers the amount of research carried out. This could be supported by more peer reviewed publications;
- State of the art modelling is applied on the national scale;.
- Ammonia gap research has provided much insight in the emission – deposition modelling and dry deposition parameterization, leading to good correlations with observations and performing on the national scale; Based on this comparison with observations RIVM concludes that the uncertainty in the estimated ammonia deposition is 30% on the national scale;
- Ammonia gap research provided changes in the dry deposition parameterization for grassland and indications that the effectiveness of manure incorporation techniques should be lowered;
- On the local scale uncertainties in the estimates of the deposition are up to 70%. This is mainly due to the lack of monitoring data to constrain the results and the uncertainty in dry deposition estimates. More

measurements in different ecosystems of dry deposition would be needed to improve and test parameterizations;
- More experiments to evaluate the local scale emission – deposition relationships are needed to determine the uncertainty in emissions and in deposition. A more mechanistic description coupling emission and deposition processes is required;
- From a scientific standpoint we recommend to be careful, given the current state of knowledge to go into too detailed policy applications, but this choice is up to the end user.

Background

National scale

- The dispersion and deposition of ammonia is estimated using the OPS model, which is extensively described by van Jaarsveld (2004) and is maintained and tested against measurements in the Dutch air quality monitoring network. On the local scale passive sampler measurements are carried out in more rural areas and in nature reserves;
- The available literature does not show that there has been a follow-up on the recommendations of the review of models of MNP in 2005 that stated: "we strongly recommend to compare OPS with models that have more detailed treatment of transport, mixing and chemistry." At RIVM there have been actions on this and publication in peer reviewed journals is essential;
- A lot of effort has these past years been directed to the explanation of the 'ammonia gap', the difference between observed ammonia concentrations and those based on OPS. The ammonia gap is basically an overestimation of the concentration of ammonia by the OPS model. Some important shortcomings have been revealed both in the deposition parameterization for agricultural soils (grassland) as well as in emission modelling. This has been done mostly focussed on model evaluation: comparison of modelled versus measured concentrations of ammonia. However, model evaluation should be done as a mass consistent approach (all input versus all output) using all end points (concentrations and deposition) of the model in comparison to emissions, because a change in one parameter affects most others. Especially dry deposition monitoring is lacking to do a complete mass consistency validation;
- There is also an uncertainty contribution of other ammonia emission sources, such as housing systems and its daily and seasonal variation. This makes it difficult to draw conclusions from a national evaluation of models by concentration and deposition measurements. More specific field campaigns such as the Veld campaign are essential to evaluate the model on individual aspects and of individual sources;
- The OPS model is evaluated every year against measurements carried out by RIVM in the framework of the Dutch air pollution network: LML. The monitoring network consists of 8 stations for NH_3. The stations are well distributed around the country. The results of the comparison are quite good for relevant components. It is important to note that the comparison is carried out for components with different physical and chemical

properties including nitrogen oxides and ammonia. This suggests that relevant processes where these properties play a role are treated correctly in the model. The comparison shows no systematic bias for nitrogen oxides and ammonia.
- The above comparison between measured and modelled concentrations yields different results depending on the scale. On the national scale the combination of monitoring stations and models provides a strong constraint leading to a limited uncertainty in the estimates of deposition.
- Based on the comparison studies done in the past and especially the Veld study it is concluded that on a national scale the quality of OPS seems satisfactory. This could also lead to the conclusion that on average for the Netherlands OPS should function well.

Local or regional scale
- On a local scale the uncertainty is no doubt larger than on the national scale because different processes have more influence, especially the dry deposition process and there monitoring stations that could provide constraints are lacking. Also the dry deposition process depends strongly on the ecosystem type. Validated parameterisation of the dry deposition to these ecosystems is in general limited;
- For individual ecosystems of 500 x 500 m2 up to 5 x 5 km^2 the uncertainty is estimated by RIVM to be 70% for NHx deposition;
- Tests of the parameterisation of the dry deposition module in OPS have been carried out by comparison with experiments including heathland, forest and unmanured grassland. This is essentially a limited number of ecosystems. Extrapolation to other ecosystems is done using the DEPAC model. Although the DEPAC model is state of the art this extrapolation increases uncertainty to the estimated deposition to ecosystems. It should be noted however that this procedure is still a large effort and, compared on an international scale, state of the art.
- Dry deposition experiments have been performed in the past for a limited set of vegetation types. The experiments do not cover the whole spectrum such as all different ecosystems with the Natura 2000 status. Dry deposition experiments are needed to parameterise models for other land use components, such as dunes, crops, etc.
- Recently there have been several additional dry deposition experiments aimed at testing the parameterisation used in DEPAC , but these have not been published so far and the results have not yet been incorporated in the parameterization of OPS;
- The use of the compensation point is state of the art. However, there is a 'grey area' between emission and deposition: is the compensation point due to the same sources as the emission, does this mean less deposition or more emission? It is recommended to go into the next step of emission – deposition modelling that addresses the dynamic equilibrium that is the driving force of both emission as deposition. This is currently done in ecosystem models;
- In order to merge measurements with modelling for mapping concentration and deposition on the local scale, correction factors are used for merging OPS results with measurements: for dry deposition of

NHx leads to the introduction of a systematic bias in the mass consistency of the model. Therefore, there should be a correction based on total mass (dry, wet, aerosol).

Overall

The scientific review of emission and deposition methods and models cannot be viewed separately from its application in policy. Since the beginning of this century investment in further developments both in emission and deposition experiments and in model improvement has been poor o.a. due to lack of funding. At the same time, there is a growing use of available methods in increasingly detailed policy applications. Examples are the discussions on the GCN and GDN-maps, PAS, etc.

At this local scale, however, there is a general lack of data needed for detailed modelling of the emission – deposition relationships, such as activity data, manure management, application rates and timing, etc. Furthermore, there is a lack of measurements and validation of these local applications. At this stage the uncertainty in the estimate of deposition on a local scale is estimated to be nearly 70%.

It is up to the end user to determine whether this would prevent the data and models to be used in the different applications at the local scale. From a scientific standpoint we recommend to be careful, given the current state of knowledge to go into too detailed applications.

Finally, the review team recommends to include more scientists with different backgrounds (agronomy, physics, chemistry) and affiliation to the group that carry out measurements and develops the emission models. In a public sensitive field of research, multiple institute support to the science underlying decision making is essential.

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11-4-2012

Literature used for the review

Cited literature in the Cover notes on emission and deposition

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Cover notes on emission and deposition

(will be provided by Gerard Velthof)