Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

CEH Edinburgh
Bush Estate
Penicuik
Midlothian, EH26 0QB
United Kingdom
Telephone +44 (0) 131 4454343
Main Fax +44 (0) 131 4453943
www.ceh.ac.uk

Prof. dr. M.J. Kropff
Vice-President Executive Board / Rector Magnificus
Wageningen University and Research Centre
Wageningen
The Netherlands

15 May 2013

Dear Professor Kropff

Please find attached my summary for the **"Review on scientific underpinning of ammonia emissions factors and ammonia deposition models"**.

Evidence presented

The following evidence has been provided for this process:

A. Documents on ammonia emission factors
B. Documents on ammonia deposition
C. Documents on the paper by Sintermann et al. (2011, Biogeosciences) on ammonia emission from manure spreading
D. Dutch national review on ammonia emission and deposition research prepared by A. Hensen, J. Duyzer, E. Lantinga and J.W. Erisman.
E. International peer review on items A-D prepared jointly by O. Hertel and S. Gyldenkaerne (Denmark)
F. International peer review on items A-D prepared by P. Cellier (France).

Terms of Reference

1. To consider the key issues raised by the national and international reviews (D, E, F), where necessary drawing on the supporting information (A-C), in relation to the following four questions:
    a) Are the emission factors for application of manure as used in the Netherlands based on scientifically sound research?
    b) Is the scientific underpinning for the differences 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?
    c) What are the gaps in knowledge in the scientific underpinning of ammonia emission factors, which demand for field measurements of ammonia emission?
    d) Is the scientific underpinning of the Dutch modelling of the dispersion and deposition of ammonia sufficient and scientific sound?

2. To moderate any major points of disagreement between the international reviewers, in order to provide a clear position on the above questions, while recognizing current scientific uncertainties.
3. To prepare a short summary statement that can be provided to the Dutch Parliament for translation and public use, and which should be understandable to non-specialists.

Competence

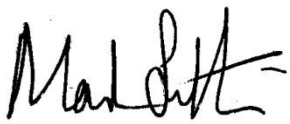
My research over the past 26 years has focused primarily on atmospheric ammonia, including its emission, atmospheric chemistry, deposition, and environmental effects. This has included experimental flux measurements, air concentration monitoring and atmospheric modelling at local and regional scales. I have published around 200 peer review papers, and am currently co-chair of the Task Force on Reactive Nitrogen (of the United National Economic Commission for Europe), chair of the International Nitrogen Initiative (INI, a joint project of IGBP and SCOPE) and a member of the Steering Group of the Global Partnership on Nutrient Management (GPNM). I previously coordinated the NitroEurope Integrated Project and currently coordinate the ÉCLAIRE project, funded by the European Commission. Recent international reports that I have coordinated include the “European Nitrogen Assessment” (prepared for the European Union, the European Science Foundation and the UNECE Convention on Long-range Transboundary Air Pollution) and the Global Overview on Nutrient Management “Our Nutrient World” (prepared for the United Nations Environment programme by the GPNM and INI).

Summary Report

I here append my summary report to this letter, which I trust meets your needs.

Please do not hesitate to contact me in case of further enquiries.

Yours sincerely,



Professor Mark A. Sutton

Summary Report: Mark Sutton, 15 May 2013.

General comments

1. Ammonia is a critical air pollutant of high policy relevance, which is currently regulated under Dutch law and European agreements (e.g. Gothenburg Protocol, National Emissions Ceilings Directive). Livestock manures are the main source of emission. While the present review focuses on land-application of manures, estimation of total ammonia emissions also depends on sound quantification of ammonia emissions from the other sources, including animal houses, grazing and fertilizer application.
2. I agree with the international reviewers that the Netherlands has been a global leader in ammonia emissions estimation, the development of emission mitigation methods, and their application by the farming community. This leadership has been reflected in the co-chairmanship of the UNECE Task Force on Reactive Nitrogen (TFRN) by the Netherlands, which has until now provided a key opportunity for the Netherlands to set the agenda on ammonia science and policy internationally.
3. However, much of the Dutch scientific underpinning dates from the 1980s and 1990s. Fewer new scientific studies have been emerging in the last 5-10 years, reflecting a reduced investment in ammonia research by the Netherlands. This is also indicated by the Netherlands proposing to withdraw from its international leadership of the TFRN from 2013. *These changes reflect an increasing stagnation of Dutch ammonia research, where the Netherlands is on a fast track to lose its leading position*.
4. The international reviewers recognize that there is an increasing body of evidence with many new developments published in the international literature from which the Dutch programme of emissions estimation and atmosphere modelling would benefit.
5. I agree with the international reviewers that the National Review document (D.) is presented at a rather general level, with only limited technical detail. It appears to combine contrasting views, and has not reached the necessary level of consensus to answer unambiguously the four key questions set. Nevertheless, sufficient evidence is available from the documentation to answer these questions.

a) Are the emission factors for application of manure as used in the Netherlands based on scientifically sound research?

6. ***Essential summary: Yes, but becoming rather out-of-date as new measurement techniques advance internationally.***
7. The international reviewers agree that the historical expertise of Dutch researchers represents a scientifically sound basis to estimate ammonia emissions from manure application. In particular, they agree that the widespread use of field-scale techniques exploiting the principles of micrometeorology (such as the Integrated Horizontal Flux, IHF) method is to be preferred to the use of chamber measurements. This is because micrometeorological methods exploit natural environmental conditions, and do not disturb the ground surface. By contrast, measurements using closed chambers alter environmental conditions at the surface, and can lead to both over-estimates of emissions (from highly ventilated chambers) and under-estimates of emissions (from chambers with restricted ventilation). Since the Dutch emission factors are largely based on robust micrometeorological results they can be considered as based on a sound foundation.

8. The international reviewers note the ongoing developments, including the use of other micrometeorological methods (such as aerodynamic gradient method and eddy covariance), and recent differences in flux estimates as reported by a review of Sintermann et al. (2011). Such methods require larger field areas and are therefore more complex to implement. In my view this new evidence builds-upon (rather than contradicts) the existing databases established using the IHF approach. (The somewhat smaller emission rates estimated by Sintermann et al. (2011) may be related to a lower dry matter content of the slurries used in some other countries, which results in better slurry infiltration to the soil and smaller emissions. This possibility deserves more detailed investigation.)
9. By contrast, *regional/national emission factors should not be directly derived from chamber studies*. Chamber measurements can form an important part of a scientifically sound strategy to understand and quantify ammonia emissions from manure application, under specific criteria: a) the purpose is to understand treatment differences rather than provide absolute emission estimates, b) emission models are used to interpret the results, allowing them to be related to field conditions, rather than extrapolated directly.
10. Variation in emission rates as observed in experimental studies can be related to a) differences in meteorology (temperature, wetness, turbulence), b) differences in soil conditions and manure type (e.g. as this affects slurry infiltration rate) and c) differences in manure application rate and method. The interaction of these factors naturally leads to substantial variation in emission rates, so that the effectiveness of low-emission techniques needs to be evaluated by combining datasets measured at several times and places.

b) Is the scientific underpinning for the differences 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?

11. ***Essential summary: Yes, but ongoing efforts are needed to quantify better the effects of differences in manure properties and farmer implementation.***
12. The major differences between the estimated effectiveness of different low emission manure spreading methods are clearly supported by the underlying measurements. A qualitative *effectiveness ranking* that is broadly supported by the international community (e.g. the Ammonia Guidance Document, of the UNECE Convention on Long-range Transboundary Air Pollution) would be: deep injection > sod/shallow injection > trailing shoe > trailing hose > reference method (surface spreading).
13. The international reviewers highlight that some details of this performance ranking would benefit from further field demonstration (i.e., the relative effectiveness of sod injection vs. trailing shoe) according to specific context (e.g. with plant canopy type and height). However, there is overall support that the mitigation approaches listed are effective to reduce ammonia emissions as estimated. The UNECE Task Force on Reactive Nitrogen has identified these low-emission slurry application methods as the ‘number one’ priority for ammonia mitigation strategies.
14. The international reviewers note that consistency of the Dutch estimates may be improved by incorporating data from international studies and by taking explicit account of *slurry dry matter content* in the emission factors. Further data should be collated and published on the *activity data* on manure application, including manure form, application techniques, soils and mitigation performance in different field contexts (e.g. experimental versus on-farm).

c) What are the gaps in knowledge in the scientific underpinning of ammonia emission factors, which demands for field measurements of ammonia emission?

15. ***Essential summary: In future, emission factors should be increasingly based on the application of continuous (real-time) ammonia flux measurement methods, combined with interpretation using process-based modelling, allowing differences in treatments and measurement methods to be understood and better quantified.***
16. The existing datasets on ammonia emission measurements in the Netherlands and elsewhere have mainly been based on time integrated method, with low temporal resolution. This leads to a limited ability to relate emission rates to rapid temporal variations in environmental conditions. New generation continuous ammonia detectors should be applied in further field scale (micrometeorological) studies to better understand the relationships between emissions and environmental conditions.
17. Other factors, such as slurry dry matter content, ammoniacal nitrogen content and acidity (pH) affect ammonia emission rates, especially as these interact with soil surface characteristics (infiltration rate) and the type of overlying plant canopy. Future measurements should include these effects more explicitly in the construction of emission inventories. For example, the Dutch emission inventory should explicitly account for activity data on slurry dry matter, also to see the extent to which changes in dry matter content of slurry in recent years can explain estimated changes emission rates observed in experimental studies (cf. Sintermann et al., 2011).
18. Future measurements should integrate a programme on emissions from slurry application to land with other field sources, such as grazing, fertilizer application, allowing for bi-directional exchange (i.e., the occurrence of both emission and deposition fluxes).
19. All measurements should be made with sufficient supporting information to allow their interpretation using process based models, such as the VOLT'AIR model. Such process-based models hold the potential to explain why the emission rates differ between different field experiments – as the effects of environmental conditions, soil surface and application methods are integrated in these models.
20. Future research should integrate sociological aspects of how farm advisors and farmers put into practice specified ammonia mitigation techniques, and to consider which aspects are most critical to their effectiveness at the farm and regional scales.
21. Modelling should also be made at the farm scale, integrating all component sources, and issues of effectiveness in relation to farm-scale decision-making, taking account of the other co-benefits of a 'full nitrogen approach' (e.g. the additional benefits for water quality and greenhouse gas mitigation associated with improvement in nitrogen use efficiency).

d) Is the scientific underpinning of the Dutch modeling of the dispersion and deposition of ammonia sufficient and scientific sound?

22. ***Essential summary: At a basic level, current approaches are sound and sufficient to demonstrate the effectiveness of existing Dutch mitigation measures. However, international advances in atmospheric modelling need to be grasped, which will be essential to assess the extent to which climate change worsens the ammonia problem.***
23. The Dutch modelling of ammonia dispersion and deposition represents a mature scientific area based on sound concepts and long interaction with the international scientific community. For many purposes the approaches used match to the complexity required for

operational tasks, such as spatial comparison of modelled ammonia concentrations in the atmosphere with measurements and the evaluation of temporal trends.

24. In the past an 'ammonia gap' has been highlighted by modellers. In the late 1990s it was initially thought that the measures in the Dutch ammonia policy had not been effective, however, this simply reflected the need for further years monitoring data. With sufficient data, it was subsequently shown that the trends in reducing measured ammonia concentrations matched the modelled expectations (e.g. Bleeker et al., 2009, in *Atmospheric Ammonia*, Springer). Subsequently, the 'ammonia gap' has referred to the ongoing difference between modelled and measured ammonia concentrations in the Netherlands. While many reasons may be adduced for such a difference (e.g. model uncertainties, spatial variation, dry deposition rates, emission rates), such differences are typical of present day comparisons of models and measurements. In my view, the Dutch 'ammonia gap' on its own does not therefore provide strong evidence of a regional overestimation in ammonia emissions.
25. While several papers have been published associated with Dutch modelling of atmospheric ammonia dispersion and deposition, both reviewers agree that more effort should be given to publishing the core description of the atmospheric modelling approaches used by the Netherlands in the peer review literature.
26. The Dutch atmospheric modelling for ammonia can be distinguished into Local Scale (e.g. sub-20 km) and Regional (national / international) scale modelling.
    a. For the local-scale, the model formulation uses a steady-state Gaussian approach, which is suitable for the purposes of evaluating local variation in concentrations.
    b. For the regional-scale, the model uses a Lagrangian approach with first order chemistry and average meteorological conditions. As one of the reviewers notes, while adequate for several purposes (e.g. evaluation of basic trends and spatial patterns), this approach does not represent the international state-of-the-art.
27. The international state-of-the-art for regional/long-range modelling is provided by 3-dimensional Eulerian models, which are currently advancing rapidly. These offer key advantages in a) allowing explicit treatment of non-linear interactions in the treatment of atmospheric chemical processes, b) coupling of emission and deposition processes to real time changes in meteorology, which may lead to further non-linearity. In practice, these advances will provide the models with a better foundation to deliver robust support in evaluating Dutch and international ammonia policies (e.g. effectiveness of abatement measures, relationship between meteorological, soil and management variation and emissions/air concentrations, temporal dynamics to relate to effects on ecosystems and human health, such as through particulate matter formation).
28. While further work is needed on bidirectional treatment of ammonia dry deposition, a key priority must be to revise emission modules to incorporate the environmental dependencies of emissions (including bidirectional exchange), so that emissions and deposition are directly coupled to meteorological variation (see further discussion in Sutton et al. 2013, *Philosophical Transactions of the Royal Society of London*). The full development of such an approach, which needs to combine various process-based model descriptions, is not yet state-of-the-art. However, it will be critical to assess the extent to which ammonia emissions can be expected to increase under future climate change.
29. The Dutch ammonia policy analysis would benefit by Dutch scientists being more strongly engaged in these new research developments, as these will lay the foundation for mechanistic explanation of both temporal differences (daily, monthly etc) and long-term trends.