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# The ALFAM2 database on ammonia emission from field-applied manure: Description and illustrative analysis

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## ABSTRACT

Ammonia ($NH_3$) emission from animal manure contributes to air pollution and ecosystem degradation, and the loss of reactive nitrogen (N) from agricultural systems. Estimates of $NH_3$ emission are necessary for national inventories and nutrient management, and $NH_3$ emission from field-applied manure has been measured in many studies over the past few decades. In this work, we facilitate the use of these data by collecting and organizing them in the ALFAM2 database. In this paper we describe the development of the database and summarise its contents, quantify effects of application methods and other variables on emission using a data subset, and discuss challenges for data analysis and model development. The database contains measurements of emission, manure and soil properties, weather, application technique, and other variables for 1895 plots from 22 research institutes in 12 countries. Data on five manure types (cattle, pig, mink, poultry, mixed, as well as sludge and "other") applied to three types of crops (grass, small grains, maize, as well as stubble and bare soil) are included. Application methods represented in the database include broadcast, trailing hose, trailing shoe (narrow band application), and open slot injection. Cattle manure application to grassland was the most common combination, and analysis of this subset (with dry matter (DM) limited to < 15%) was carried out using mixed- and fixed-effects models in order to quantify effects of management and environment on ammonia emission, and to highlight challenges for use of the database. Measured emission in this subset ranged from < 1% to 130% of

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applied ammonia after 48 h. Results showed clear, albeit variable, reductions in $NH_3$ emission due to trailing hose, trailing shoe, and open slot injection of slurry compared to broadcast application. There was evidence of positive effects of air temperature and wind speed on $NH_3$ emission, and limited evidence of effects of slurry DM. However, random-effects coefficients for differences among research institutes were among the largest model coefficients, and showed a deviation from the mean response by more than 100% in some cases. The source of these institute differences could not be determined with certainty, but there is some evidence that they are related to differences in soils, or differences in application or measurement methods. The ALFAM2 database should be useful for development and evaluation of both emission factors and emission models, but users need to recognize the limitations caused by confounding variables, imbalance in the dataset, and dependence among observations from the same institute. Variation among measurements and in reported variables highlights the importance of international agreement on how $NH_3$ emission should be measured, along with necessary types of supporting data and standard protocols for their measurement. Both are needed in order to produce more accurate and useful ammonia emission measurements. Expansion of the ALFAM2 database will continue, and readers are invited to contact the corresponding author for information on data submission. The latest version of the database is available at http://www.alfam.dk.

## 1. Introduction

Ammonia ($NH_3$) emission from animal manure and synthetic fertilizers constitutes a large loss of reactive nitrogen (N) from agricultural systems (Bouwman et al., 2011). For agriculture, N loss from manure represents a cost, since it must be replaced with synthetic or additional organic fertilizer (Sutton et al., 2011). For society, $NH_3$ in the atmosphere is implicated in particulate formation and associated health impacts, and contributes to ecosystem degradation when it is deposited on land or water (Bobbink et al., 2010; Sutton et al., 2011; Erisman et al., 2013). Indirectly, $NH_3$ emission also contributes to $N_2O$ emission by increasing the rate of nitrogen cycling in natural ecosystems that receive deposited $NH_3$ (Davidson, 2009).

Globally there is consensus that agriculture, and in particular livestock manure, is the largest source of $NH_3$ and ammonium ($NH_4^+$) in the atmosphere (Beusen et al., 2008). The main sources are manure (urine and faeces) in animal houses, stored manure, and manure applied to fields. In many countries, emission from manure handled as slurry is the single largest source of $NH_3$ to the atmosphere, and emission from field-applied slurry is a major part of this (Hutchings et al., 2001; Rotz et al., 2014). Accurate estimates of $NH_3$ emission are important for national inventories, field- and farm-scale N budgets, and to evaluate the effect of emission reduction practices as part of improved nutrient management. Therefore, a large number of experiments on $NH_3$ emission from livestock manure applied to fields have been carried out in the past few decades (see reviews by Webb et al., (2010) and Sintermann et al., (2012)), and several models for estimating $NH_3$ emission have been developed (e.g., Søgaard et al., 2002; Rotz et al., 2014; Langevin et al., 2015). Standardisation of experimental results and collection in a database can increase the utility and accessibility of experimental data, which can then be used for multiple purposes, including development or evaluation of both emission factors and models. The ALFAM project on $NH_3$ emission from field-applied manure demonstrated this: the resulting database and the related ALFAM model (Søgaard et al., 2002) have been widely used (215 citations as of 17 August 2017 according to Google Scholar). But many emission measurement experiments have been carried out since the publication of the ALFAM database, and measurement techniques have been refined (Sintermann et al., 2012). Preservation of these emission measurements, which have been used to determine emission factors, along with supporting data in an accessible (numeric) form, is essential. Given the current interest in $NH_3$ emission from both regulatory and research perspectives, expansion and improvement of the ALFAM database is needed.

The primary objective of this article is to present the ALFAM2 database, which consists of data from the original ALFAM database and new data. The ALFAM2 database contains about twice as many observations as ALFAM, and provides more information by adding new variables related to emission. In this article, we: 1) describe and summarise the new ALFAM2 database; 2) use statistical models to attempt to quantify effects of application methods and other factors on emission, 3) discuss challenges for data analysis and model development based on the database, and 4) recommend ways to standardize and improve the quality of ammonia emission measurements.

## 2. Methods

### 2.1. The ALFAM2 database

#### 2.1.1. Data collection

The database described in this work is a combination of the original ALFAM database (Søgaard et al., 2002) and newer data. New data were entered into a spreadsheet template by each research group that collected them, or transferred to the template from other files provided by the group. Research groups in Europe, Canada, and the US known to us to have made $NH_3$ emission measurements were invited to submit data. (New contributions are also welcome, and readers are invited to contact the corresponding author for information on data submission.) The following types of variables were included: identification (project, publication, experiment, field, plot code, treatment), location (latitude, longitude, topography, field name), soil (texture, moisture, pH, temperature, tillage), weather (air temperature, wind speed, precipitation, relative humidity, solar radiation), manure (source, bedding, dry matter, total ammoniacal nitrogen (TAN), pH, treatments), application (time, method, rate, incorporation), crop (type, height, coverage), and emission (interval time, measurement method, plot size, background $NH_3$ (g) concentration upwind of the emitting surface, average emission rate). Two types of data were collected: plot-level (concerning a single physical plot from which emission was measured) and measurement interval-level (concerning a single time interval with one estimate of $NH_3$ emission rate, for a single physical plot). Plot-level data included plot identification, location, soil, manure, application, and crop data. Measurement interval-level data also included weather and emission for each interval, which varied in length among experiments and within individual plots. Weather data included average air temperature, wind speed, and precipitation for each interval. Emission data were reported as average $NH_3$ flux (typical unit, kg $ha^{-1}$ $h^{-1}$) for each measurement interval. Application methods and emission measurement methods (McGinn and Janzen, 1998) were selected from a list of possibilities or defined by the submitter.

#### 2.1.2. Data processing, calculations, and database organization

All data processing and analysis was done using R version 3.3.1 (R Core Team 2017). The general steps were:

1 Data from the original ALFAM study were read from a spreadsheet file, and column names and factor levels were added.
2 Minor changes were made to ALFAM data (described directly