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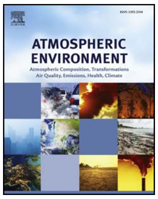

A model for estimating seasonal trends of ammonia emission from cattle manure applied to grassland in the Netherlands

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ABSTRACT

Field data on ammonia emission after liquid cattle manure ('slurry') application to grassland were statistically analysed to reveal the effect of manure and field characteristics and of weather conditions in eight consecutive periods after manure application. Logistic regression models, modelling the emission expressed as a percentage of the ammonia still present at the start of each period as the response variable, were developed separately for broadcast spreading, narrow band application (trailing shoe) and shallow injection. Wind speed, temperature, soil type, total ammoniacal nitrogen (TAN) content and dry matter content of the manure, application rate and grass height were selected as significant explanatory variables. Their effects differed for each application method and among periods. Temperature and wind speed were generally the most important drivers for emission.

The fitted regression models were used to reveal seasonal trends in NH_3 emission employing historical meteorological data for the years 1991–2014. The overall average emission was higher in early and midsummer than in early spring and late summer. This seasonal trend was most pronounced for broadcast spreading followed by narrow band application, and was almost absent for shallow injection. However, due to the large variation in weather conditions, emission on a particular day in early spring can be higher than on a particular day in summer. The analysis further revealed that, in a specific scenario and depending on the application technique, emission could be reduced with 20–30% by restricting manure application to favourable days, i.e. with weather conditions with minimal emission levels.

1. Introduction

1.1. Background

Handling of manure on farms results in the emission of ammonia (NH_3) which has a negative impact on the environment. Ammonia contributes to acidification and eutrophication of ecosystems (Bobbink et al., 2010; Erisman et al., 2011; Sutton et al., 2011). Therefore, directive upper limits are set for national NH_3 emissions in Europe (EC, 2001). Each country also has to report an estimate of the national yearly emission. Moreover, compulsory and voluntarily measures have been introduced to reduce the emissions from housing of animals, storage of manure and manure application to farm land. The general objective of this study was to improve the estimation of NH_3 emission from field-applied manure, and to identify practical measures to further reduce NH_3 emission. The latter may become necessary, for instance when the number of animals increases, when national ceilings become more restricted, or when further reduction of NH_3 emission is needed at a more regional scale, e.g. near nature reserve areas susceptible to N deposition (EC, 2016).

The NH_3 emission from field-applied manure significantly contributes to the total national NH_3 emission from manure, for example 32% in Denmark, 42% in the Netherlands and 46% in Switzerland (Mikkelsen et al., 2014; Van Bruggen et al., 2015; Kupper et al., 2015). In the Netherlands cattle manure application amounts to circa 70% of total emission from field-applied manure, and 57% of all field-applied manure is applied to grassland, predominantly as cattle manure (Van Bruggen et al., 2015). Therefore this study was restricted to NH_3 emission from cattle manure application to grassland.

Many studies show that the method of application has a large impact on the emission from field-applied manure, see e.g. the review by Webb et al. (2010). *Broadcast surface spreading* is the conventional application method which is carried out by a tanker fitted with a splash-plate. In contrast, the application methods *narrow-band application* and *shallow injection* are lower in emission, and these methods are therefore compulsory for grassland in the Netherlands. Narrow-band application

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(trailing shoe) is carried out by trailing narrow sliding shoes over the soil surface, pushing aside the grass cover without cutting the grass sward, and releasing manure at the back of the shoe leaving narrow bands of manure on the soil surface. Shallow injection employs injection coulters that cut V-slots into the soil. Manure is released into the slots, which are then left open. Both low-emission application methods also result in increased availability of nitrogen (N) and thus increased yields of grassland (Huijsmans et al., 2016).

The so-called emission factor (EF) of an application technique is generally defined as the percentage total emission in kg ammonia-N relative to the total ammoniacal nitrogen applied (TAN). Based on 199 experiments in which manure was applied on grassland, the current. EFs for the Netherlands are 74% for broadcast spreading ($n = 81$), 26% for narrow-band application ($n = 29$), and 16% for shallow injection ($n = 89$), see Huijsmans and Schils (2009). The current total national emission estimate resulting from manure application to grassland is based on these EFs in combination with the estimated share of each application technique and an estimate of the amounts of applied manure (Velthof et al., 2012).

1.2. Objective

NH_3 emission from field-applied manure is extremely variable. This is generally attributed to differences in application method, weather, field and manure characteristics. In the United Kindom (Misselbrook et al., 2012) and in Denmark (Mikkelsen et al., 2014) the effects of the time of application within a year and of manure characteristics on the EF are used to improve the estimate of national emission. However, this can not be generalized to Europe because the mechanisms controlling NH_3 emission from slurry are too complex to be reliable for the wide range of conditions and application methods found in European agriculture (Sommer and Hutchings, 2001). Although it has been demonstrated that emission in the Netherlands is related to application method, weather, field and manure characteristics (Huijsmans et al., 2001, 2003), only application methods are currently used to differentiate between emission factors in the Netherlands.

The general objective of this study was to improve EF estimates, by employing weather, field and manure characteristics, and to identify measures abating NH_3 emission. More specifically the objective was threefold: (1) to model the effect of fluctuating weather conditions during the full four days following manure application using a sequence of regression models; (2) to use the resulting sequence of fitted regression models to predict ammonia emission throughout the year, using historical meteorological data, in order to reveal seasonal trends; (3) to employ the model to estimate to what extent emission can be reduced when manure application would be tuned to specific favourable weather conditions.

1.3. Approach

The effect of wind speed, air temperature and other factors on the emission process can partly be explained in a mechanistic way by the chemical and physical processes leading to the volatilization of NH_3 (Van der Molen et al., 1990a, 1990b; Génermont and Cellier, 1997; Sommer and Olesen, 2000; Sommer et al., 2003; Beuning et al., 2008; Loubet et al., 2010). These effects were also confirmed in many empirical studies (Sommer and Olesen, 1991; Sommer et al., 1991; Sommer and Ersbøll, 1994; Menzi et al., 1998; Huijsmans et al., 2001, 2003; Søgaard et al., 2002; Misselbrook et al., 2005; Häni et al., 2016). Most empirical approaches employed a single regression model for the total emission period of say four full days. In such a model total emission, in kg-N ha^{-1} or percentage of TAN applied, is related to the mean temperature and wind speed in the total emission period, and to other explanatory variables such as TAN content, application rate and grass height. Some of these studies model the emission rate, in kg-N ha^{-1} h^{-1} or percentage of TAN-applied per hour, rather than the emission itself.

However, the effect of air temperature, wind speed and other explanatory variables on the volatilization of NH_3 is most likely not constant over the whole volatilization period. Air temperature, for example, may be more important during the first stages of volatilization because the fluid part of the manure has not yet been fully infiltrated into the soil. In contrast, at later stages the solid fraction of the manure is mostly on top of the soil and may still contribute to NH_3 losses. This different effect at different stages was recognized by Sommer et al. (1991) and Sommer and Olesen (1991), who developed separate regression models for Denmark, for four time periods (shifts) after slurry application. They showed that the effect of an explanatory variable might vary depending on the progress of the volatilization process. The approach in the present study is similar to the Danish study, but uses regression models for eight time shifts, instead of four. These time shifts result from the measuring intervals used in the field experiments on volatilization of NH_3 in the Netherlands. Explanatory variables used here are weather conditions, and manure- and field-characteristics. The fitted models can be used to calculate the emission for each shift separately, which can then be summed over all shifts, resulting in a total emission.

2. Materials and methods

2.1. Data

The data used for analysis were recorded in various experiments on the volatilization of NH_3 after liquid manure application on grassland in the Netherlands since the late 1980's. To obtain a homogeneous data set in terms of manure characteristics, only experiments with untreated cattle manure were selected. All experiments reported here were carried out with full scale, commercially available machinery, and with slurries and slurry application rates as used on grassland in practice. Experiments were carried out from February until October under different field and weather conditions. Data are partly published in Huijsmans et al. (2001), Huijsmans and Schils (2009) and Huijsmans et al., (2015a,b). The data used in this study are available as supplementary material (Annex A).

For each field experiment, the volatilization of NH_3 was determined using the micrometeorological mass balance method (Denmead, 1983; Ryden and McNeill, 1984). Details of the plot lay-out and measuring protocol are reported by Huijsmans et al. (2001). The emissions and weather data were recorded at various consecutive time intervals (shifts), within a 96 h time span after manure application. All experiments started in the morning and the duration of the eight successive time intervals was approximately 1.5, 1.5, 3, 3, 15, 24, 24, and 24 h, i.e. four relatively short shifts during the first 9 h when volatilization rates are highest, one longer shift covering the first evening and night, and finally three shifts of 24 h. In some experiments, the first shift was originally split up in two shorter shifts. For the purpose of this study, the data of these shorter shifts were combined to one shift of 1.5 h. Some other experiments had very different timings of the shifts. As the intended analysis per shift is only meaningful when the timing of the shifts after application is comparable for all experiments, experiments with very different timings were omitted from the analysis.

The volatilization conditions during the experiments, i.e. the weather and the characteristics of the manure, grass and soil, were recorded as possible explanatory variables for NH_3 emission. Weather variables recorded during each shift were air temperature, relative humidity and radiation at a height of 1.5 m above ground level, and wind speed at a height of 2 m above ground level. The manure was sampled directly from the manure application device, and was analysed for total N, total ammoniacal nitrogen (TAN), dry matter content (DM) and pH. The manure application rate (m^3 ha^{-1}) was measured by weighing each application tank before and after manure application and by measuring the field size. The density of the manure was assumed