MODELLING AMMONIA EMISSIONS AFTER FIELD APPLICATION OF ANAEROBIC DIGESTED SLURRIES

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1 INTRODUCTION

In Germany, the production of biogas from energy cropping systems has been in the focus of the national bio-energy strategy for the reduction of greenhouse gas emissions since the year 2004. In contrast to other biogas production systems, the focus in the new generation of biogas production is on a high energy output which requires a high share of crop input in addition to co-fermented animal slurries. Biogas plants exclusively supplied with crop substrates are also quite common. As a result, due to the new mixture of substrates as input material, fermentation residues (anaerobic digested slurries) may show different characteristics as compared to (digested) animal slurries. The aimed for greenhouse gas saving benefit of biogas production can be potentially strongly decreased by other adverse environmental effects induced by biogas systems as greenhouse gas and ammonia emissions. Ammonia emissions, which are unavoidable as anaerobic digested slurries have to be re-transferred to the field as N-fertilizers, contribute indirectly to greenhouse gas emissions (Wulf et al.2002). In addition, they are the main source of eutrophicating and acidifying compounds deposited on natural and semi-natural ecosystems. There is thus an urgent need to quantify NH_3 emissions from the new type of biogas production systems. For scenario and regionalisation simulations, model approaches for NH_3 emissions after field application of anaerobic digested slurries are of particular interest. There is still a lack of both, experimental testing of NH_3 emissions after application of anaerobic digested slurries and modelling of the processes causing the attached particular emission patterns. In addition to mechanistic models, which are a prerequisite for proper understanding of processes underlying NH_3 emissions, empirical models are of interest for testing of the influence of different factors on NH_3 losses and for the prediction of NH_3 losses under practical conditions.

Model development can only be carried out on an extensive experimental basis for robust estimation of model parameters. Therefore, a high number of ammonia loss field measurements were carried out in the years 2007 -2009 in biogas cropping systems grown in Northern Germany, consisting of simultaneous measurement of NH_3 losses from animal and anaerobic digested slurries in multiple-plot field experiments with different N-fertilization levels. For the determination of NH_3 emissions micrometeorological as well as plot based measurement approaches were used and subsequently cross- checked. Ammonia losses after field application of anaerobic digested slurries in energy crop rotations and animal slurries were modelled with one new dynamic and one empirical model approach. In addition to the well known principles for calculation of ammonia losses based on temperature, pH and soil water relationships new algorithms were implemented to test and to account for the effects of slurry incorporation, crop type, canopy structure and precipitation on NH_3 emissions.

2 MATERIALS AND METHODS

2.1 Ammonia loss measurements

The models were tested and parameterized based on a dataset obtained during 3 years (2007-2009) of NH_3 loss measurements in multi-plot field trials with 4 different organic fertilizers, 3 locations and 5 crop rotations. Crop rotations included silage maize (*Zea maize*), silage wheat (*Triticum aestivum*) as well as perennial (*Lolium perenne*) and annual (*Lolium mulitflorum*) rye grass. Crop rotations were planted in three typical agro-regions of the federal state of Schleswig-Holstein, Northern Germany: in the fertile, moraine derived hilly landscape in the East close to the Baltic Sea, low fertility sandy soils in the centre and fertile alluvial marshland at the Western North Sea coast. Model development was based on the simultaneous measurement of NH_3 losses in conventional agronomic multi-plot field trials consisting of 96 – 240 plots (12 m x 12 m) per study site. Tested organic fertilizers included anaerobic digested slurries from exclusive fermentation of energy crop substrates (mono-fermented) and derived from animal slurries and energy crop material as substrates (co-fermented), pig slurry and to a lesser extent cattle slurry. Altogether 18 experimental campaigns for simultaneous determination of NH_3 losses from different slurries were carried out covering a wide range of slurry properties, canopy and weather conditions. Emissions from the plots were determined in four replicates by passive flux sampling which can be converted into absolute quantitative losses with transfer coefficients (Vandré and Kaupenjohann 1998). These transfer coefficients were derived from simultaneous measurements with a calibrated dynamic chamber method (Pacholski et al. 2006) in the multi-plot field trials as well as by the micrometeorological backwards Lagrangian stochastic dispersion technique (Sommer et al. 2005) applied on adjacent fields. Both methods showed a very good agreement (Pacholski et al. 2009).

2.2 Simple mechanistic model

A simple mechanistic model was developed on the basis of a model by Sommer and Olesen (2000). The model considers only processes in the slurry/soil mixture at the top of the soil and in the atmosphere above it. The emission of NH_3 from the gaseous phase of the soil into the atmosphere above the soil/canopy is explicitly calculated by a resistance approach (Eq. 1).

$$F_V = \frac{1}{r_a + r_b + r_c} \cdot ([C_N] - [C_A]) \qquad \text{(Eq. 1)}$$

F_V denotes the NH_3 flux to the atmosphere above the soil or canopy, $[C_N]$ the NH_3-N concentration at the surface of the slurry/soil mixture, $[C_A]$ the NH_3-N concentration in ambient atmosphere, r_a the resistance within the turbulent layer above the soil or canopy, r_b the resistance within the laminar boundary layer above the soil or canopy and r_c the resistance within the crop canopy and slurry layer.

Basic shortcomings of the original approach were the neglect of the effects of canopy structure, slurry infiltration, drying of slurry surface and crust formation, precipitation, incorporation of slurry into the soil and nitrification on NH_3-emissions. Based on field and laboratory data these effects were integrated in the new model. The specific effect of grass swards on ammonia emissions was included by considering the effect of leaf area expansion on NH_3 emissions.

2.3 Empirical model approach

As a second approach an empirical model based on a Michaelis-Menten-type equation (Eq. 2) was applied (Sogaard et al. 2002):

$$N(t) = N_{\max} \frac{t}{t + K_m} \qquad \text{(Eq. 2)}$$

This equation describes the dynamic process of cumulative ammonia loss, $N(t)$, over time, t. Similar as in the ALFAM model approach (Sogaard et al. 2002), the parameters N_{max}, maximum ammonia loss at infinite time, and K_m, point in time when 50% of N_{max} is reached, were modeled as functions of explanatory variables including slurry type, canopy type, leaf area index (LAI), ammoniacal N concentration, temperature, wind speed, precipitation and others. The multiplicative method was selected to avoid negative model values for N_{max} or K_m (Eq 3), with the letters x_i for explanatory variables in the exponent and values A_i and B_i for connected parameters which are estimated during model fitting for N_{max} and K_m, respectively.

$$N_{\max} = A_0 \times A_1^{x_1} \times \cdots A_m^{x_m} \quad \textit{and} \quad K_m = B_0 \times B_1^{x_1} \times \cdots B_m^{x_m} \qquad \text{(Eq. 3)}$$

N_{max} and K_m values for the measurements were derived by fitting of Eq. 2 to the time curves of the measured fluxes which were subsequently used for parameterization and validation of the model. For comparison purposes measured final losses were also used in the model evaluation.

For model evaluation R^2 values and absolute model deviation (*RMSE*) were calculated. Model development and statistical testing were carried out in ModelMaker® and with R statistical software package.

3 RESULTS AND DISCUSSION

3.1 Mechanistic Model

The mechanistic model (Eq.1) could reproduce measured NH_3 loss dynamics, simulated values always being very close to the observed ones as shown for two parameterization data sets presented in Fig. 1. Although there were minor discrepancies, the general trend was depicted as observed during measurements. Simulations with the mechanistic model showed a good agreement with measured final cumulated NH_3 losses at both study sites for the validation set consisting of 6 measurement campaigns with 3 simultaneously applied organic fertilizers (R^2 0.61, RMSE 1.95 kg N ha^{-1}, Fig. 2). The regression line between measured and simulated values is very close to the 1:1 line with an intercept close to zero. In some cases the model deviated to a higher degree from measured values. This was always one outlier out of the three slurries applied at one application date. This indicates that the general processes of NH_3 emissions as related to weather, slurry and canopy conditions were sufficiently described by the model. The outliers are mainly attributed to uncertainty of input parameters, in particular to slurry characteristics.

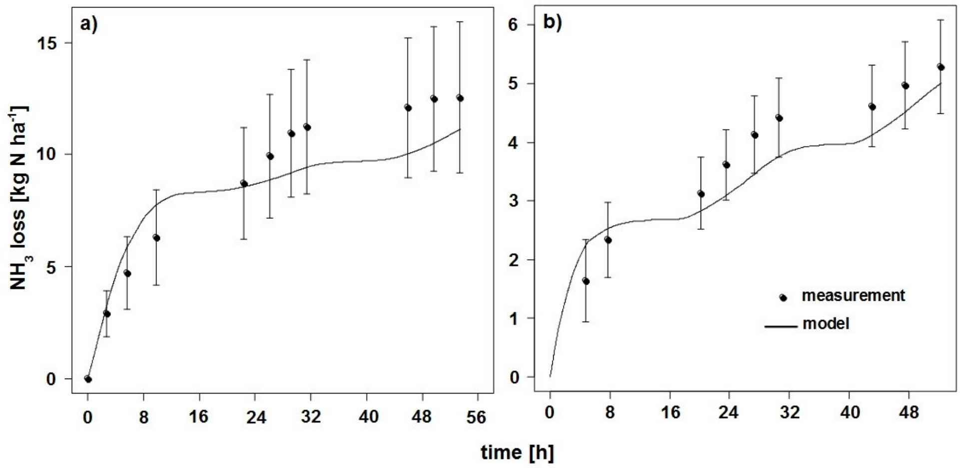

FIGURE 1 **Measured NH_3 loss dynamics from mono-fermented anaerobic digested slurries (only crops used in fermentation) applied to grassland sites with trail hoses and simulated NH_3 loss dynamics by the mechanistic approach (Eq. 1) for two parameterization data sets a) May 2007, sandy soil, 60 kg N_{tot} ha^{-1} b) May 2008, sandy soil, 120 kg N_{tot} ha^{-1}; error bars = std. dev. (n=4))**

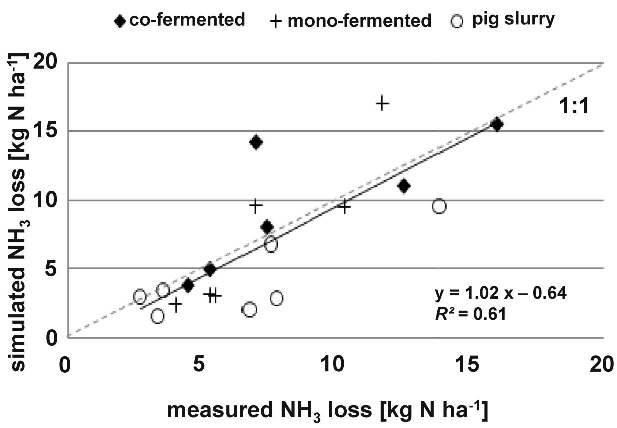

FIGURE 2 **Simulated cumulated NH_3 emissions in relation to measured losses after application of anaerobic digested and pig slurries, validation data set (RMSE 1.95 kg N ha^{-1}), mono-fermented = crop substrates, co-fermented = crops + animal slurry**

3.2 Empirical Model

Calculations with the empirical model approach for NH_3 emissions (Eq. 2 and Eq.3) showed a good fit to maximal losses of the parameterization data set (Fig. 3 a, R^2 0.81, RMSE, 3.18 kg N ha^{-1}). Due to the low number of measurements with cattle slurry the prediction power was considerably lower (4.07 kg N ha^{-1}) as for the other slurries. This also applies for the validation data set (Fig. 3 b). The agreement with the maximal emissions from pig and anaerobic digested slurries of the validation set was similar to the prediction power for the parameterization data set (RMSE: pig slurry 1.36 kg N ha^{-1}, anaerobic digested slurry 2.71 kg N ha^{-1}). With respect to measured final losses from pig and anaerobic digested slurries the RMSE values were 0.94 and 1.78 kg N ha^{-1}, respectively. The accuracy of model prediction was in the range of measurement accuracy of commonly used NH_3 loss measurement techniques (Pacholski et al 2006).

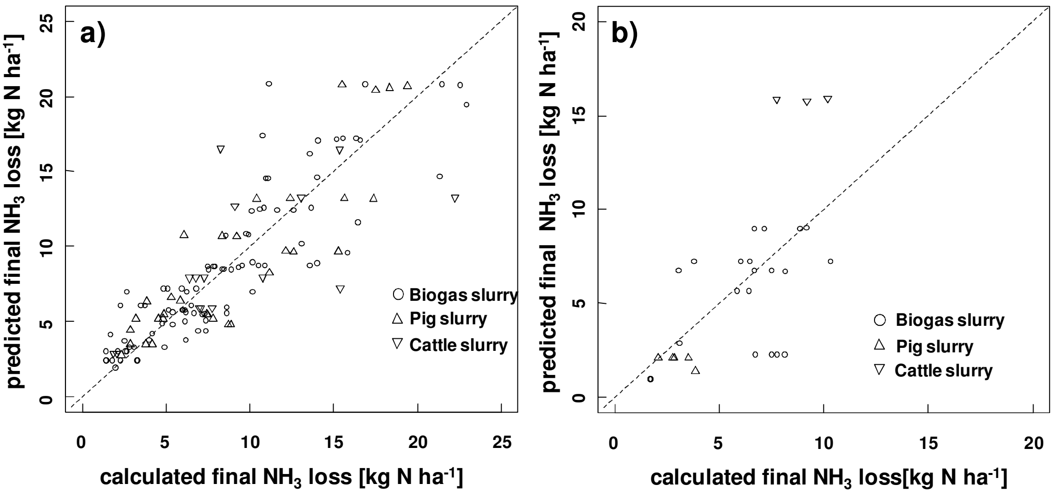

FIGURE 3 **Measured NH_3 fluxes from three organic fertilizers (biogas slurry = anaerobic digested slurry) applied to arable and grassland sites and simulated losses by the empirical approach (Eq. 2 and Eq. 3) for a) parameterization data set and b) final cumulated NH_3 losses in a validation data set**

4 CONCLUSIONS

The mechanistic as well as the empirical model approach were proven to be applicable for the simulation of NH_3 emissions from arable land and grassland sites after application of anaerobic digested and pig slurries. Due to a low number of measurements both models could not successfully fitted for cattle slurry. Anaerobic digested and pig slurries could be simulated with the same set of variables and parameters. Ammonia emissions after application of anaerobic digested slurries behave thus according to the same physic-chemical principles as animal slurries.

ACKNOWLEDGEMENTS

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