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Ammonia emission after slurry application to grassland in Switzerland

Christoph Häni[a,*], Jörg Sintermann[b], Thomas Kupper[a], Markus Jocher[b], Albrecht Neftel[b]

[a] School of Agricultural, Forest and Food Sciences, Bern University of Applied Sciences, CH-3052 Zollikofen, Switzerland
[b] Agroscope, Institute for Sustainability Sciences ISS, CH-8046 Zürich-Reckenholz, Switzerland

HIGHLIGHTS

- We conducted 17 field experiments on NH_3 emission after slurry application.
- Emissions after slurry broadcast application ranged from 10% to 47% of TAN.
- Examined abatement techniques proofed to be efficient in reducing emissions.
- A regression analysis was performed.
- Air temperature and slurry dry matter were important predictor parameters.

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ABSTRACT

Loss of ammonia (NH_3) after field application of livestock slurry contributes between 30% and 50% of agricultural NH_3 emissions from European countries. The objectives of this study were to re-evaluate NH_3 emissions following application of cattle and pig slurry to grassland in Switzerland and to investigate the effectiveness of abatement techniques. In 17 field experiments, NH_3 emissions were determined with a micrometeorological approach, relating the emission to the measured concentration by means of atmospheric dispersion modelling. The cattle slurry applied exhibited an average dry matter content of 3.3% (range between 1.0% and 6.7% dry matter). The emission after application of cattle slurry spread with a splash plate (referred to as reference technique) ranged from 10% to 47% of applied Total Ammoniacal Nitrogen (% of TAN) and averaged to 25% of TAN. This range of losses is lower by approx. a factor of two compared to measurements from earlier Swiss experiments. Applications with trailing hose and trailing shoe systems yielded an average reduction of 51% and 53%, respectively, relative to the reference technique. A regression analysis showed that the dry matter content of the slurry and the air temperature are important drivers for NH_3 emission.

1. Introduction

Ammonia (NH_3) emissions in Europe are dominated by the agricultural sector (Van Der Hoek, 1998). Field application of livestock slurry is a key source, contributing between 30% and 50% of total emissions in European countries for liquid manure systems (Reidy et al., 2008) which represent more than half of the manure production in most central European countries (Menzi, 2002). National emission inventories in European countries are calculated annually using nitrogen flow models that include the emission stages of grazing, housing, storage and field application of livestock manure. Emissions of the individual stages are estimated as the product of the nitrogen flow through a stage (e.g. Mg N yr^{-1}) and its related emission factor (EF). EFs are fixed individually for the national inventories (Reidy et al., 2008) or based on emission guideline documents such as the EMEP/EEA air pollutant emission inventory guidebook (EEA, 2013).

Based on an analysis of published data, Sintermann et al. (2012) found a large range of EFs for broadcast application of slurry. Surprisingly, medium plot sizes, typically circles with 40 m diameters, showed systematically higher EFs than larger sized field-plots. Other factors such as air temperature or dry matter (DM) content of the slurry showed no correlation to the emission level. This is in clear contradiction to many other investigations that focused on specific influencing factors which especially showed a dependency from the DM content, with higher emissions resulting from greater DM contents (e.g. Misselbrook et al., 2005; Sommer and Hutchings, 2001). A large share of the data in Sintermann et al. (2012) that are based on measurements using medium plot sizes originates from the Netherlands (Huijsmans et al., 2001, 2003) and from Switzerland (Menzi et al., 1998). The Dutch experiments covered a DM range from 5% to 15%, while the Swiss data exhibited lower DM contents (1%–7%). Recent measurements in Switzerland, carried out

* Corresponding author.
E-mail address: christoph.haeni@bfh.ch (C. Häni).

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between 2006 and 2010 (Ammann et al., 2012; Sintermann et al., 2011a, 2011b; Spirig et al., 2010), yielded EFs 50% lower than the first generation data from Switzerland. These newer measurements were performed under agronomical conditions similar to the ones used by Menzi et al. (1998) with regard to crop cover, soil properties, timing of application, a DM content of the slurry between 1% and 5% and an average application rate of 30 m^3 ha^{-1}.

In this paper, we present results from a new series of NH_3 emission measurements at several sites of the Swiss plateau. Since NH_3 emissions after slurry application generally show a rapid decline over the first few hours (e.g. Huijsmans et al., 2001; Spirig et al., 2010) we employed custom-built impinger sampling systems to measure NH_3 concentration with a high time resolution. For the determination of the emissions from the measured NH_3 concentrations, we used a backward Lagrangian stochastic (bLS) dispersion model (Flesch et al., 2004). The primary aim was to re-evaluate EFs for slurry application with a focus on spreading of cattle slurry using a splash plate. Additionally, other factors which might influence the emissions were investigated: the experimental plot size, the application technique, the slurry characteristics and the timing of application.

2. Material and methods

2.1. Field experiments

In total, 17 field experiments were performed between summer 2011 and spring 2014 (Table 1). The field experiments were carried out at five different sites in the Central Plateau of Switzerland (Table 2). At four locations the vegetation cover consisted of a temporary ley and at one site of natural grassland. Application of slurry was done using a tractor pulled tanker.

Slurry was applied onto two to four rectangular plots with standard plot dimensions of approx. 30 m by 30 m. The slurry application duration was between 3 and 10 min per plot and time lags between the slurry applications of different plots were kept as short as possible (approx. 30 min). The areas covered with slurry and the positions of all instruments were recorded by a Global Positioning System (GPS Trimbel R8 GNSS, approx. precision 10 cm). The target application rate for all experiments was 30 m^3 ha^{-1}, which is the typical application rate in Switzerland. Immediately after application, one NH_3 sampling device (Section 2.2) was positioned at the centre of the plot and the measurement was initiated. The sampling started with short intervals which were then gradually increased as the emissions decreased. The background NH_3 concentration was measured upwind of the experimental area with sampling intervals of 4–8 h. Measurements of wind velocity and background NH_3 concentration were started before slurry application. The duration of emission measurements lasted between 17 and 120 h, but in most cases more than 36 h (Supplementary material I). For each plot, two samples of slurry were taken from the tanker: one before and one after application. The slurry samples were stored at 4 °C until they were analysed in the laboratory. For the determination of the emissions, we used the atmospheric dispersion model 'WindTrax', a bLS model (Flesch et al., 2004) (Section 2.3).

Three field experiments (F1 to F3) were carried out to identify potential differences in NH_3 emissions due to the source area size (Table 1). Emissions from standard size plots were compared with emissions from field-scale plots. The dimensions of the field-scale plots were approx. 5000 m^2. In experiment F1, a third plot with a size of 100 m^2 was investigated. During slurry application on field-scale plots, it was necessary to refill the slurry tanker twice which delayed the subsequent application operation by roughly 30 min. As a consequence, the field-scale plots could not be treated as homogeneously emitting source areas and the emission rates of the individual tracks were fitted to a bi-exponentially decaying time course assuming identical time behaviour (Sintermann et al., 2011a) for the first few hours, where differences in the emission rates were considerable. Afterwards, the field was treated as a homogeneous emission source. Fourteen field experiments were performed in order to compare application techniques (A1 to A6), slurry characteristics (S1 to S6), and application timing (T1 and T2). Application techniques were splash plate (SP, reference technique), trailing hose (TH), trailing shoe (TS) and shallow injection (SI). Slurry types included slurry from dairy cows (CS) and pig slurry from fattening pigs (PSf) and breeding pigs (PSb). Experiments S4 to S6 were carried out using CS with a DM content between 4.9% and 6.7%, which is higher than the average for slurries used in Switzerland (Flisch et al., 2009).

Additionally in three experiments (T1, W1, W2), the results from the bLS method were compared to results from an independent mass balance method (integrated horizontal flux, IHF) using concentrations and wind measurements at 4 to 6 different heights. One comparison was part of the experiment T1 and two additional comparisons (W1, W2) took place at the site Witzwil. Further information on the applied IHF method is provided in the Supplementary material II.

2.2. Automated impinger sampling devices

NH_3 air concentrations were measured using automated impinger sampling devices (low cost impinger systems: LOCI), also known as acid traps. Ambient air was drawn through a threaded midget impinger with a volume of 22 mL (64712-U, Supelco) containing 15 mL of a 0.01 M sodium acetate buffer solution at pH 4. The NH_3 was retained in the acidic solution as ammonium (NH_4^+). A small amount of dichloromethane was added to prevent decomposition of NH_4^+ by microbial activity. The sampled NH_4^+ concentration was determined in the laboratory by spectrophotometry (DR2800, Hach Lange GmbH). On each LOCI system, seven impinger positions were run subsequently and at two heights (between 0.6 m and 1.6 m above ground level) simultaneously. One additional position was used as a blank probe, exposed but without air flow through the solution. The individual measurement heights are provided in the Supplementary material III. The interval length for each sampling position was set prior to the sampling start on an automation module (Siemens Logic Module) ranging from 10 to 30 min in the first hours after spreading and over 1–6 h during the rest of the time. This automated sampling system guaranteed temporary high resolution sampling without the necessity for on-site control. The air flow through the impinger tubes was kept at approx. 0.7 L/min and logged every 30 s. The NH_3 collection efficiency of the impinger, operated at a flow rate of 0.7 L/min, was higher than 99% for the range of NH_3 concentrations expected to occur in the ambient air.

2.3. Emission estimation with a dispersion model

The bLS model that was used for the determination of the emissions in all 17 field experiments is described in detail by Flesch et al. (2004). The model is incorporated in the WindTrax software (http://www.thunderbeachscientific.com; version 2.0.8.8) in the form of the inverse mode (backward in time) option. It calculates the concentration to emission ratio of finite homogeneous source areas embedded in an area with no biosphere-atmosphere exchange. In order to obtain a unique solution for all present source areas, at least one concentration measurement within each emission plume must be available.

The following input parameters are required to run the model: the friction velocity u_* (m s^{-1}), the roughness length z_0 (m), the Obukhov length L (m), the standard deviation of the rotated wind