Reassessment of Swiss ammonia emission factors after slurry application

Häni Christoph[1*], Sintermann Jörg[2], Neftel Albrecht[2], Kupper Thomas[1]
(1) Bern University of Applied Sciences, School of Agricultural, Forest and Food Sciences, 3052 Zollikofen, CH
(2) Research Station Agroscope Reckenholz-Tänikon ART, 8046 Zürich, CH
*Corresponding author: christoph.haeni@bfh.ch

Abstract
New measurements of ammonia (NH_3) loss after slurry application on grassland in Switzerland were carried over the last two years. They yielded NH_3 emissions being by approximately 50% lower compared to earlier published values in the 1990s. A reassessment of the previous experiments revealed experimental shortcomings that do explain most of the difference.

Introduction
The Swiss model Agrammon [1] for the calculation of the national emissions of ammonia (NH_3) within the framework of the UN Convention on Long-range Transboundary Air Pollution [2] uses currently an average emission factor (EF) of 50% of the applied total ammoniacal nitrogen (TAN) for broadcast application which is considered as the reference technique. For low emission application techniques such as trailing hose and trailing shoe, specific factors for emission reduction (70% and 50% of broadcast, respectively) are used. The EF for broadcast application is mainly based on the ALFAM model [3] and on measurement in Switzerland from the 1990s [4,5]. Recent measurements for Swiss conditions exhibited significantly lower emissions [6,7] that could not be explained and the hypothesis of a potential plot scale influence on EF was stated [8]. Consequently, a new measurement campaign was launched at different sites in Switzerland to reveal potential influences of used plot scales and to clarify the differences. This study presents the results from the current campaign and discusses the reasons for the discrepancy between the previous and the new results.

Material & Methods
Field sites and agronomical issues
A first series of trials (module 1) examined whether an influence of the plot scale on the EF's exists. The slurry was applied with slurry tankers equipped with a splash plate, or a trailing hose. Plots of medium size (30m x 30m) were compared to field size plots of 0.5 ha. A second series (module 2) was devoted to investigate the influence of application technique, type of slurry and seasonality on medium size plots (30m x 30m). All experiments were carried out on grassland and application rates amounted to approximately 30 t/ha. The ammonia loss was measured for 2-3 days. Table 1 shows a compilation of the trials.

Measuring technique
At the centre of each plot, an impinger based sampling device measured the NH_3 concentration at two heights (approx. 0.9m and 1.6m). Additionally, the background concentration was sampled up wind of the manured areas. The impinger sampling systems [6] were operated at a flow rate of approx. 0.7 L/min and sampling intervals between 10 min at application start and several hours over night. Wind velocity and temperature fluctuations were measured with 3D sonic devices. The measurements were terminated when an emission flux could no longer be detected (i.e. when the concentrations above the plots were equal or below the inflow concentrations).

WindTrax approach

For each NH_3 sampling device, the ratio of the measured concentration to the related emission rate (C/E) was calculated using the backward Lagrangian stochastic Model (bLS) WindTrax [9]. The model input was given by 10 minute averages of the wind direction, the friction velocity (U*), the Obhukov-Length (L) and the roughness length (Zo), as well as the standard deviations of the rotated high frequency wind velocities. Emission rates were then calculated by dividing the measured NH_3 concentrations less the measured background concentration by the C/E ratios averaged over the sampling intervals.

$$\bar{E}_{calc} = \frac{C_{meas} - C_{BGD}}{\overline{C/E}_{WindTrax}} \quad (1)$$

Table 1. Cumulative losses of NH_3 on grassland sites in Switzerland after application of slurry. Application techniques: splash plate (SP), trailing hose (TH), trailing shoe (TS) and shallow injection (SI). (DM = dry matter content)

Module	Date	Site	App. Tech.	Slurry Type	TAN (g/L)	DM (%)	App. Rate (t/ha)	Plot Size (m^2)	Loss NH_3 (% TAN)
1	21.09.2011	Tänikon	SP	Cattle	1.06	3.7	27.8	137	25%
1	21.09.2011	Tänikon	SP	Cattle	1.06	3.7	28.0	1027	22%
1	21.09.2011	Tänikon	SP	Cattle	1.05	3.6	31.6	5359	27%
1	08.11.2011	Posieux	SP	Cattle/Pig	1.19	2.1	27.2	985	16%
1	08.11.2011	Posieux	SP	Cattle/Pig	1.16	1.5	28.8	6029	17%
1	10.05.2012	Hohenrain	TH	Cattle	0.73	2.6	29.0	1296	7%
1	10.05.2012	Hohenrain	TH	Cattle	0.73	2.8	27.3	5040	5%
2	14.07.2011	Tänikon	SP	Cattle	1.06	3.7	23.3	1417	29%
2	14.07.2011	Tänikon	TH *	Cattle	1.05	3.6	31.0	1360	22%
2	14.07.2011	Tänikon	TH **	Cattle	1.04	3.6	31.1	1470	13%
2	12.03.2012	Posieux	SP	Cattle	0.71	3.4	24	1094	12%
2	12.03.2012	Posieux	TH	Cattle	0.72	3.7	18.8	1759	8%
2	12.03.2012	Posieux	TS	Cattle	0.72	3.1	25.1	994	5%
2	15.03.2012	Wengi	SP	Cattle	1.2	2.4	28.3	1077	11%
2	15.03.2012	Wengi	SP	Sows	1.8	2.2	26.8	1078	12%
2	15.03.2012	Wengi	SP	Fattening pigs	2.2	3.4	26.4	1063	11%
2	24.05.2012	Wengi	SP	Cattle	1.6	3.8	25.7	1135	32%
2	24.05.2012	Wengi	SP	Sows	1.8	3.3	26	1082	15%
2	24.05.2012	Wengi	SP	Fattening pigs	1.6	1.3	28.9	967	22%
2	04.07.2012	Posieux	SP	Cattle	0.70	3.0	26.7	968	31%
2	04.07.2012	Posieux	TH	Cattle	0.70	3.4	22.6	1480	8%
2	04.07.2012	Posieux	TS	Cattle	0.69	2.5	19.2	979	8%
2	14.08.2012	Posieux	SP	Cattle	0.68	2.7	18.6	1043	27%
2	14.08.2012	Posieux	TH	Cattle	0.69	2.8	22.5	1367	15%
2	14.08.2012	Posieux	TS	Cattle	0.69	2.7	27.6	954	12%
2	14.08.2012	Posieux	SI	Cattle	0.68	2.6	24.2	1092	7%
2	27.08.2012†	Tänikon	SP	Cattle	0.85	3.1	30.6	1554	20%
2	28.08.2012††	Tänikon	SP	Cattle	0.85	3.1	28.9	1593	17%
2	28.08.2012†††	Tänikon	SP	Cattle	0.85	3.1	29.2	1515	28%
2	14.11.2012	Posieux	SP	Cattle	0.72	1.0	28.2	1043	15%
2	14.11.2012	Posieux	TH	Cattle	0.72	1.0	31.5	1367	7%
2	14.11.2012	Posieux	TS	Cattle	0.65	1.5	25.7	954	10%
2	19.11.2012	Wengi	SP	Cattle	1.65	3.8	26.7	925	19%
2	19.11.2012	Wengi	SP	Sows	1.66	1.0	24.6	1008	10%
2	19.11.2012	Wengi	SP	Fattening pigs	1.60	1.4	25.5	921	13%

Height of the vegetation: 10 cm (*); 18 cm (**). Application of slurry: in the evening (†); in the morning (††); at noon (†††)

Results & discussion

The calculated cumulative loss of NH_3 is given in Table 1. Module 1 (see the upper part in Table 1) did not yield statistically different values for field size and medium size plots, thus a dependence of the emissions from the plot size was not found. Consequently medium size plots produced reliable results. The presented emissions for splash plate were low as compared to the levels found in other European countries [3]. This might be due to the low dry matter (DM) content of the slurries. In addition, the soil properties of the Swiss sites might favour a fast ammonium absorption.

Figure 1 shows the range of emissions of the measurements in comparison with the previous Swiss studies for broadcast application. The present study mostly confirms the lower values found in more recent studies [6,7] compared to previous investigations [4].

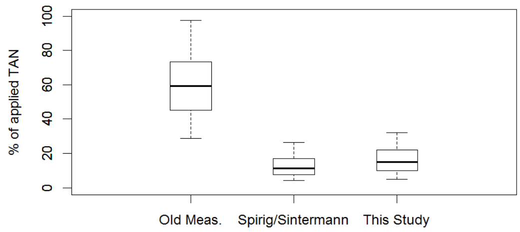

Figure 1. Boxplots showing the median (bold line), interquartile range (Box) and total range (whiskers) of cumulative NH_3 loss at Swiss grassland sites obtained by Menzi et al. [4], Sintermann et al. [6]/Spirig et al. [7], and from this study.

A reassessment of the previous measurements [4] showed a combination of several factors that led to a systematic overestimation. We do briefly recall the approach used in the former measurements from the 1990s. The trials were carried out using circular plots with a diameter of 40m. Passive diffusion samplers were used to measure the NH_3 concentration. The resulting emission rates were calculated using the ZINST-Method after Wilson et al. [10]. Wind speed measurements were carried out using cup anemometers with a very low threshold speed. All measurements were carried out at the experimental site Tänikon. A more detailed experimental design of the previous experiments can be obtained from Katz et al. [5].
We identified three factors that caused biases toward an overestimation of the NH_3 emissions.

Wind speed measurements
We found a significant overestimation of wind speed measurements, which could be attributed to the behaviour of the specific cup anemometers that have been used. This effect could be seen especially at low wind speeds.

Calculation of the emission rate
A recalculation of the ZINST method by the newest version of the 3D bLS WindTrax yielded different ZINST heights than Wilson et al. [10] suggested. Additionally, the choice of the roughness length Zo is crucial for the ZINST method, but not straight forward. These effects led to an overestimation of the losses in the order of 20% of the EF’s reported by Menzi et al. [4] (Figure 2).

Interference from neighbouring sources
We calculated the effect of NH3 concentration increase due to neighbouring plots as used in the 1990s. Although the distance between the individual plots was 70m we found significant overestimations of the NH3 concentrations, and therefore the cumulative losses, given unfavourable wind directions. This interference was assumed to be negligible in the original data evaluation [5].

The reduction of the low emission techniques were around 45% for trailing hose, 55% for trailing shoe and 75% for shallow injection. They are in the range of expected relative reductions from low emission techniques.

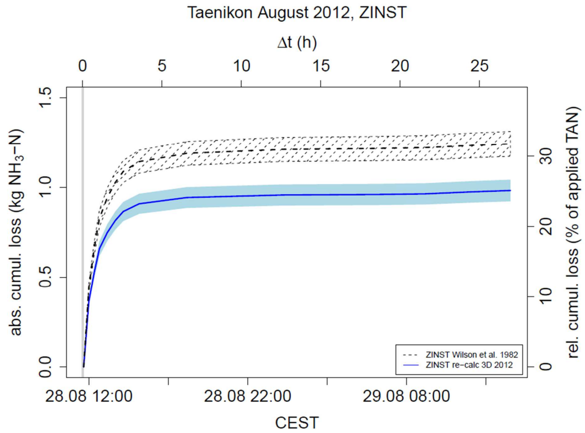

Figure 2. Cumulative NH3 loss from the "noon" plot in the August experiment at site Tänikon, calculated using the original ZINST method (dashed line) and the ZINST recalculation by WindTrax (straight line).

Conclusion

The discrepancies between previous and recent Swiss studies can be attributed to several factors inducing an overestimation of the emissions determined previously. The emission for slurry application using the splash plate was found to range between 20% and 25% of the applied TAN. The reductions obtained with low emission techniques amounted to 45% for the trailing hose, 55% for the trailing shoe and 75% for shallow injection which are within the expected range of relative reduction rates.

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