animal - open space 4 (2025) 100111

Contents lists available at ScienceDirect

animal - open space

journal homepage: www.elsevier.com/locate/anopes

Method paper

Method: A standardised laboratory method for measuring ammonia volatilisation from pig slurry using a dynamic flux multichamber system

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ARTICLE INFO

Article history:
Received 13 May 2025
Revised 12 September 2025
Accepted 15 September 2025

Handling editor: Javier Álvarez-Rodríguez

Keywords:
Environment
Mitigation strategies
Nitrogen
Repeatability
Urea

ABSTRACT

Ammonia (**NH_3**) emissions generated by animal manure represent a challenge for the current livestock system, especially in the context of pig production. Standardised methods for measuring NH_3 concentration in pig slurry are needed to assess whether specific management strategies (e.g. low-protein diets and feed additives) can reduce NH_3 emissions. Therefore, the aim of this study was to provide a standardised procedure and test the repeatability in measuring NH_3 concentration in pig slurry using a laboratory-controlled method based on a dynamic flux multichamber system. Five slurry mixes of 348 g each were prepared using spot faecal and urine samples from a single pig. Every mix was composed of 87 g of faeces, 87 g of urine, and 174 g of distilled water. For each mix, three replicates of 100 g were realised, for a total of 15 slurry replicates of five slurry mixes. The 15 slurry replicates were contained in jars, placed in a water bath (21 °C), and injected with an even flow of synthetic air (approx. 0.3 L/min). The replicates were connected to a cavity ring-down spectrometer (**CRDS**), which, combined with a multichannel sampler, measured the NH_3 concentration of the outgoing air flow from the slurry replicates for 168.75 consecutive hours. Each slurry replicate was measured cyclically for 15 min, with a 10-min interval between two slurry replicates over 168.75 h of measurements. The values recorded during the final 60 s of each 15-min period were interpolated on an hourly basis, obtaining one NH_3 concentration value per hour. To test the repeatability of the method, CVs of area under the curve for NH_3 concentration (**AUC NH_3**, ppm × h), NH_3 concentration peak value (**PV NH_3**, ppm) and time to reach the peak (**TTP**, h) were calculated within pairs of replicates from the same mix and within pairs of mixes. For the slurry mixes, all the CVs calculated showed a variation lower than 10%. Among the replicates, only the CV related to the TTP registered a value higher than 10% for four pairs of replicates out of 15. These findings suggest that the proposed dynamic flux multichamber system provides a standardised and repeatable approach for measuring NH_3 concentration in pig slurry under controlled laboratory conditions.

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Implications

The emission of large amounts of ammonia by manure derived from livestock activities has adverse effects on the environment, animal, and human health. In animal production, the impact of ammonia can be reduced through interventions involving animal diets, manure storage management, or soil fertilisation techniques. However, to verify that these mitigation strategies work, standardised methods capable of measuring ammonia levels in animal manure are needed. The proposed system is a method proven to accurately and repeatably measure ammonia concentrations in pig slurry under controlled laboratory conditions, thereby validating the effects of the tested mitigation strategies.

Specifications table

Subject	Nutrition
Specific subject area	A standardised laboratory method for measuring ammonia volatilisation in pig slurry.

(*continued on next page*)

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https://doi.org/10.1016/j.anopes.2025.100111

Type of data	Tables, figures, and images
How data were acquired	Ammonia concentration of pig slurry was measured using a dynamic flux multichamber system connected to a multichannel sampler (model A0311-s1, Picarro Inc., Santa Clara, CA, USA) and a cavity ring-down spectrometer (CRDS, model G2103, Picarro Inc., Santa Clara, CA, USA).
Data format	Raw, filtered and analysed data (.DAT, . CSV).
Parameters for data collection	Fifteen replicates of pig slurry from five slurry mixes were analysed for their ammonia concentration. The faeces and urine used for the five mixes belonged to a single pig. Each mix consisted of 84 g of faeces, 84 g of urine, and 174 g of distilled water. For each mix, three identical replicates of 100 g were obtained. The area under the curve for ammonia concentration, ammonia peak concentration and time to reach the ammonia peak concentration were calculated for each replicate and mix. The CVs were calculated for replicate pairs within the same slurry mix and among the slurry mixes for the three measurements.
Description of data collection	A total of 15 pig slurry replicates derived from five slurry mixes were analysed for their ammonia concentration over a measurement period of 168.75 h using a standardised laboratory method based on a dynamic flux multichamber system.
Data source location	Institution: Agroscope City/Town/Region: Posieux, Fribourg Canton Country: Switzerland Latitude and longitude (and GPS coordinates, if possible) for collected samples/data: 46°46′07.50″ N, 7°06′ 17.90″ E
Data accessibility	Data, codes and supplementary materials used for this paper can be obtained from the following repository. Repository name: Method: A standardised laboratory method for measuring ammonia volatilisation in pig slurry using a dynamic flux multichamber system https://doi.org/10.5281/zenodo.17201764
Related research article	None.

Introduction

Ammonia (**NH_3**) is a noxious compound that contributes to soil acidification, water eutrophication, and odour emissions (Krupa, 2003; Webb et al., 2014). At the global level, agriculture contributes more than 81% of total NH_3 emissions, among which the livestock sector is the largest contributor (Wyer et al., 2022). In Europe, the agricultural sector accounts for 94% of NH_3 emissions (European Commission et al., 2019), with pig farming alone contributing one-third of these emissions (International Institute for Applied Systems Analysis, 2017). Besides its environmental impact, NH_3 poses risks to human and animal health, particularly affecting the eyes and respiratory system (Wang et al., 2020). Ammonia concentrations higher than 25 ppm can damage the tracheal mucosa cilium and alveoli of pigs, thus making them more susceptible to respiratory diseases and impairing their overall growth performance (Wang et al., 2019). Furthermore, high NH_3 concentrations in the barn can induce a stress response in pigs. This condition causes an increase in blood parameters associated with inflammatory or immunological responses to stress (von Borell et al., 2007).

At the farm level, NH_3 originates mainly from urinary nitrogen, primarily in the form of urea, which, after excretion, is rapidly broken down into NH_3 by the faecal enzyme urease and environmental bacterial activity (Waldrip et al., 2015). By contrast, faecal nitrogen, which is mostly incorporated into bacterial proteins undergoing slow decomposition (Canh et al., 1998), plays a minor role in NH_3 emissions. Moreover, NH_3 concentration at the farm level is affected by multiple climate factors, such as temperature, air velocity, and ventilation rates (Insausti et al., 2020), which makes measuring NH_3 emissions challenging. Furthermore, NH_3 adheres to surfaces and has high solubility in water, further complicating its accurate detection in the environment (Mukhtar et al., 2002). The aim of this work is not to replace on-farm measurements, which remain essential to capturing the complexity of NH_3 emission under real conditions. Instead, we propose a complementary approach focused on the development and standardisation of a laboratory-controlled protocol using a dynamic flux multichamber system. The proposed setup then allows for a controlled assessment of the potential NH_3 emission from pig slurry, independent of farm-specific variables. Since urinary and faecal nitrogen excretion is influenced by diet, this method can also serve as a tool for evaluating the potential for NH_3 emission reduction, for instance, when the dietary CP supply differs between treatments.

Materials and methods

Equipment and system setup

A schematic representation of the proposed system is shown in Fig. 1, while images of the individual components are shown in Fig. 2. The dynamic flux multichamber system consisted of 16 identical chambers composed of 1-L perfluoroalkoxy alkane (**PFA**) jars (100-1000-01, Savillex, Eden Prairie, MN; Fig. 2a), each closed with screw caps (600-110-28, Savillex; Fig. 2b) equipped with two quarter-inch tube ports on top for the inlet and outlet of air. The 1-L chambers (height 12.34 cm; diameter 10.77 cm) had an emission surface area of 91.1 cm^2, resulting in a surface-to-volume ratio of 91.1:1.12 (cm^2:L). Of the 16 jars, 15 were filled with pig slurry, and one was kept empty to flush the system between the measurements of two different jars. During the measurement, a constant flow of synthetic air (N_2: 80%, O_2: 20%; PanGas, Dagmersellen, Switzerland) stabilised at three bars using a three-stage pressure regulator (H. Lüdi, Regensdorf, Switzerland; Fig. 1a and Fig. 2c) was directed to the 16 jars. An even flow of approximately 0.3 L/min was allowed through the jars using critical orifices (hole diameter 100 µm, Lenox Laser, Glen Arm, MD, USA; Fig. 1b and Fig. 2d). The air flow through the critical orifices was previously checked to ensure consistency and was 0.309 ± 0.109 L/min at three bars of inlet pressure. Subsequently, the

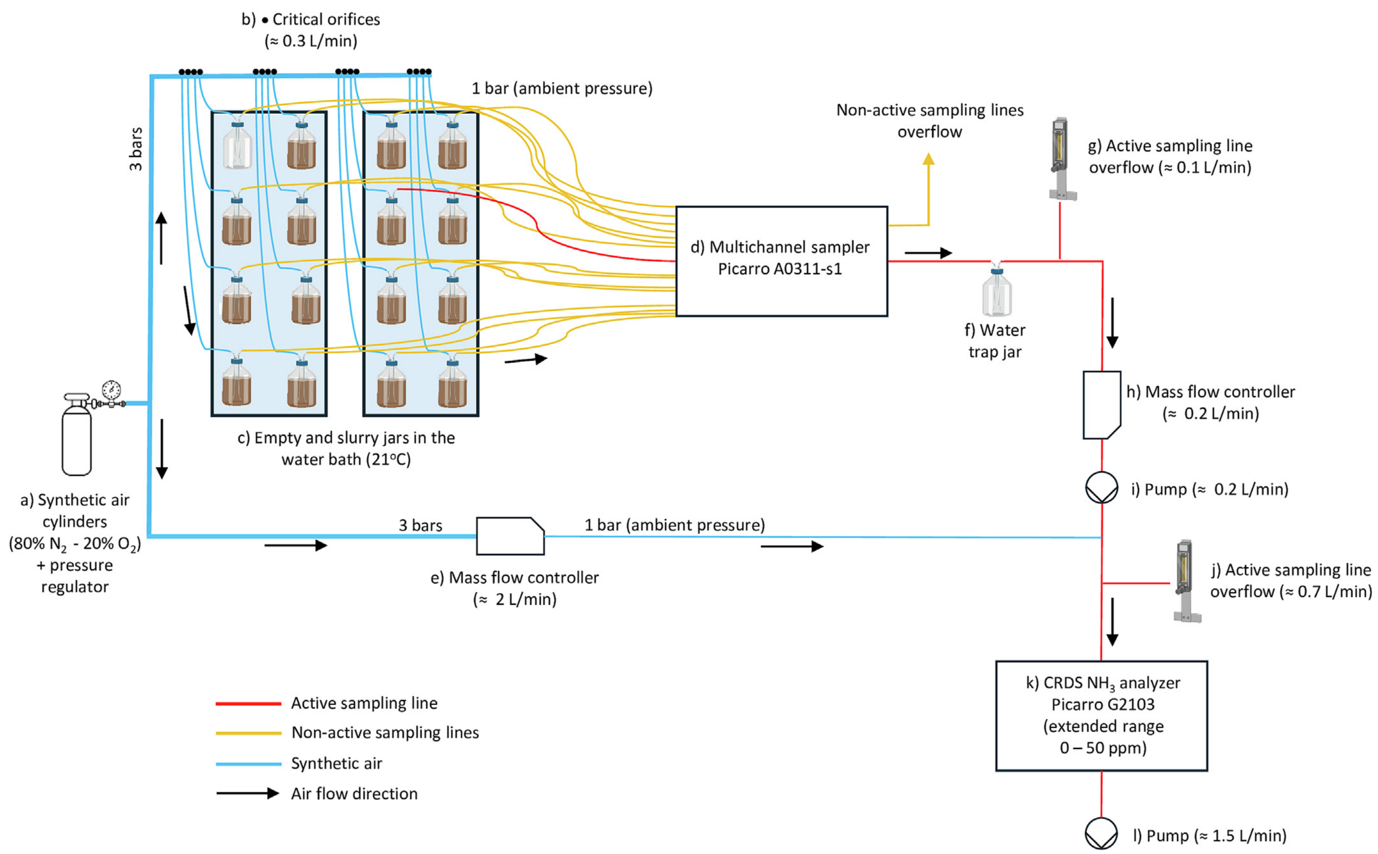

Fig. 1. Schematic representation of the dynamic flux multichamber system used to measure ammonia concentration in pig slurry replicates.

critical orifices were connected to the inlet ports on the jar caps by PFA tubes with a length of 56.0 cm (Swagelok, PFA-T4-062). The tightness of the air supply system from the synthetic air cylinders to the orifices was tested to exclude any leakage and to ensure an even flow through all jars. The test was performed as follows: a pressure gauge (Gloor, Burgdorf, Switzerland) was installed along the pipe between the pressure regulator and the critical orifices. The outlet ports of the orifices were tightly closed, and synthetic air was pumped at 5 bars into the system. The valve on the gas bottle was then closed. The pressure after 15 min was 98.3% of the original pressure, indicating good airtight characteristics of the air supply system. The outlet ports of the jars were then connected to a multichannel sampler (model A0311-s1, Picarro Inc., Santa Clara, CA, USA) (Fig. 1d and Fig. 2e) using PFA tubes with a length of 95.5 cm (Swagelok, PFA-T4-062). The multichannel sampler had 16 inlet ports and two outlet ports. One outlet port collected all exhaust gases from the non-active lines. The other outlet port was connected to a PFA water trap jar (Fig. 1f). This jar served as a safety measure to prevent possible condensation to reach the electronic components of the system. The PFA water trap used consisted of an empty PFA jar (100-0500-01, Savillex, Eden Prairie, MN) closed with a screw cap (600-089-28, Savillex, Eden Prairie, MN) equipped with two quarter-inch tube ports on top for the inlet and the outlet of the air. While the inlet port was connected to the multichannel sampler, the outlet port was connected to a mass flow controller (**MFC**, GSC-B4TT-BB23, Vögtlin Instruments Inc., Muttenz, Switzerland; Fig. 1h) to standardise the airflow at 0.2 L/min. A pump (Fig. 1i) was connected to the MFC to create the necessary underpressure. The rest of the air (approx. 0.1 L/min) was released through an exhaust overflow pipe, and a flow meter (Type 1100, Wisag AG, Zürich, CH; Fig. 1g) was connected to it to visually monitor the flow. The airflow was then diluted at 1:10 using a second MFC (Fig. 1e) directly connected to the synthetic air cylinders and set at 2 L/min. The diluted airflow was directed to the cavity ring-down spectrometer (**CRDS**, model G2103, Picarro Inc., Santa Clara, CA, USA; Fig. 1k and Fig. 2f) measuring NH_3 concentration. The CRDS aspired the air (approx. 1.5 L/min) to be analysed by means of a pump (Fig. 1l) connected to it. The excess air (approx. 0.7 L/min) was evacuated via an exhaust overflow pipe installed between the MFCs and the CRDS and equipped with a flowmeter (Type 1100, Wisag AG, Zürich, CH; Fig. 1j). The NH_3 concentrations were referenced to commercial gas standards (50 ppm NH_3, Messer Schweiz AG, Switzerland) diluted with synthetic air. The exact NH_3 concentration in the diluted standards was validated by absorption in diluted sulphuric acid and subsequent ion chromatography (ICS 3000; Thermo Scientific™ Dionex™ ion chromatography, Switzerland). During the measurement, the jars were kept in a water bath at 21 °C (Optima T100; Grant Instruments, Shepreth, UK; Fig. 1c and Fig. 2g). Throughout the measurement, the room temperature was 21.3 ± 0.1 °C and was monitored using data loggers (THM912, Oregon Scientific, Tualatin, USA). By maintaining the room temperature similar to the water bath temperature, condensation was completely prevented, resulting in no liquid in the PFA water trap jar throughout the experiment. All jars, tubes, and fittings were manufactured with PFA to minimise the absorption of NH_3 on the surfaces. PFA was chosen because it is inert to most chemicals and has a low coefficient of friction as well as low permeability to water vapour and gases (Shah et al., 2006). Similarly, all the metal parts that could be in contact with NH_3 were coated with silicon to protect against NH_3 adsorption.

Slurry mixes and slurry replicates preparation

Three days before starting the NH_3 measurement, urine and faecal samples from a pig were transferred from a −20 °C freezer to a

Fig. 2. Individual components of the dynamic flux multichamber system used to measure ammonia concentration in pig slurry replicates: (A) 1 L perfluoroalkoxy alkane jar, B) perfluoroalkoxy alkane jar screw cap with two-quarter–inch tube ports, (C) cylinders and pressure regulator used to deliver synthetic air to the system, (D) 100 μm hole diameter critical orifices, (E) multichannel sampler, (F) cavity-ring down spectrometer and G) jars in the water bath.

Fig. 2 (*continued*)

4.5 °C fridge for thawing. Samples originated from a female Swiss Large White finisher pig (70.0 kg BW) fed a standard diet (16.4% CP content). Spot faecal and urine samples were collected separately by sampling the pig directly in the pen for four consecutive days. The faecal DM content was 219 g/kg. The faecal and urine samples had faecal and urinary urea nitrogen content of 28.4 g/kg and 35.6 g/L, respectively, and were stored in a 25 × 40 cm plastic bag and a 0.5 L plastic bottle, respectively. After thawing, five slurry mixes (Mix 1, Mix 2, Mix 3, Mix 4, and Mix 5) were prepared to test the repeatability of the method when spot samples were retrieved from different spots within the faecal bag. Each mix consisted of 87 g of urine mixed with 87 g of faeces (1:1 w/w). The amount of 87 g was determined based on a total available urine amount of 435 g (87 g per mix). The 174 g slurry was mixed with an equal amount of distilled water (1:1 w/w) in a plastic beaker and blended using a single-blade hand mixer. The 1:1 mixing ratios of urine to faeces and slurry to water were determined based on a preliminary study in which the ratios ensured that NH_3 concentration remained below the detection limit (50 ppm) of the CRDS and prevented the formation of slurry crusts. The 1:1 ratio of urine to faeces is not the excretion ratio of finishing pigs, but was used only for methodological consistency. Finally, from the 348 g slurry mix, three replicates of 100 g each were transferred to three PFA jars. Overall, 15 slurry replicates were obtained, three for each of the five slurry mixes (i.e. Mix 1: M1a, M1b, and M1c; Mix 2: M2a, M2b, and M2c; Mix 3: M3a, M3b, and M3c; Mix 4: M4a, M4b, and M4c; Mix 5: M5a, M5b, and M5c).

Programming and analysing cycles of measurements

Before starting the first measurement cycle, the jars were flushed with synthetic air for 30 min. Thereafter, the multichannel sampler successively connected the 15 jars containing slurry to the CRDS for 15 min each. Before moving on to the next slurry jar, the system was ventilated for 10 min with synthetic air, using the empty jar to remove any NH_3 adsorbed to the system components. This cycle was then repeated continuously over 168.75 h. During this period, 27 cycles were completed, with each jar being measured for a total of 6.75 h. To quantify the slurry weight loss after 168.75 h, each jar containing slurry was weighed at the beginning and end of the measurement period.

Data processing and calculations

A test conducted previously showed that 14 min of adaptation was sufficient to stabilise the system at the concentration of each jar. Therefore, the values recorded during the final 60 s of each 15-min period were interpolated on an hourly basis, resulting in approximately 160 values per replicate. The area under the curve for NH_3 concentration (**AUC NH_3**; ppm × h), the NH_3 concentration peak value (**PV NH_3**; ppm) and the time to reach the peak (**TTP**; h) were calculated for every replicate. The AUC NH_3 was calculated using the trapezoidal rule according to the following formula:

$$\sum \frac{(y_1 + y_2)}{2}(x_2 - x_1)$$

where y_1 is the NH_3 concentration (ppm) at time x_1 and y_2 is the NH_3 concentration at time x_2. The interval between x_1 and x_2 is 1 h.

Fig. 2 (*continued*)

Fig. 2 (*continued*)

To assess the similarity between slurry replicates and slurry mixes, CVs were calculated for AUC NH_3, PV NH_3 and TTP. This was done for pairs of replicates within the same mix (e.g. M1a vs M1b) and for pairs of mixes (e.g. Mix 1 vs Mix 2). The value for each mix (e.g. Mix 1) was determined as the average of its three replicates (e.g. M1a, M1b, and M1c).

Given that there were five mixes, each with three replicates, this resulted in:

- 15 pairwise replicates comparisons (three comparisons per mix);
- 10 pairwise mix comparisons.

All data manipulations and calculations were performed using R (version 4.4.1, R Core Team, 2024).

Results

At the end of the measurement period, the 15 slurry jars still had, on average, 43.4 ± 2.3 g of the slurry–water mix, with a weight loss ranging from 50.5 to 59.0% (Supplementary Table S1 in https://doi.org/10.5281/zenodo.17201764).

Pairwise comparisons of slurry replicates within the same slurry mix

Considering pairwise comparisons of replicates within the same mix, the smallest difference for AUC NH_3 was observed between M2b and M2c. Replicates M2b and M2c had an AUC NH_3 of 1 057 and 1 072 ppm × h, respectively, resulting in a CV of 1.00% between them (Table 1 and Table 2). By contrast, the greatest difference in AUC NH_3 was between the two replicates M1a and M1c (M1a = 1 133 ppm × h vs M1c = 984 ppm × h; CV = 9.96%). For PV NH_3, replicates M2a and M2c showed the least variation, with values of 9.4 and 9.5 ppm, respectively, and a CV of 0.74%. The greatest difference in PV NH_3 was observed between replicates M1b and M1c (9.9 vs 8.6 ppm), resulting in a CV = 10.00% (Table 1 and Table 2). For TTP, several replicate pairs peaked at a similar time: M2b and M2c at 64 h, M3a and M3c at 65 h, and M4a and M4b at 66 h, resulting in a CV of <0.01% for these comparisons (Table 1 and Table 2). Replicates M1a and M1b reached their peak 18 h apart, resulting in a high CV = 21.22%.

Pairwise comparisons of slurry mixes

Treating each mix as the average of its three replicates, the smallest AUC NH_3 difference and the smallest CV were observed between Mix 3 and Mix 4 (1 043 vs 1 050 ppm × h; CV = 0.47%), while the largest difference and largest CV occurred between Mix 2 and Mix 5 (1 089 vs 1 008 ppm × h; CV = 5.47%) (Table 3 and Table 4). The PV NH_3 for Mix 1 and Mix 2 were similar (9.4 vs 9.3 ppm), resulting in a CV of 0.74%, whereas the greatest difference was observed between Mix 1 and Mix 4 (9.4 vs 8.7 ppm), resulting in a CV = 5.38% (Table 3 and Table 4). For TTP, the lowest CV was observed between Mix 2 and Mix 4 (63.7 vs 64.0 h; CV = 0.33%). In contrast, the largest TTP difference was found between Mix 3 and Mix 5 (65.3 vs 59.7 h; CV = 6.34%) (Table 3 and Table 4).

Author's point of views

The proposed method allowed for the accurate and precise determination of NH_3 concentration in pig slurry. By operating

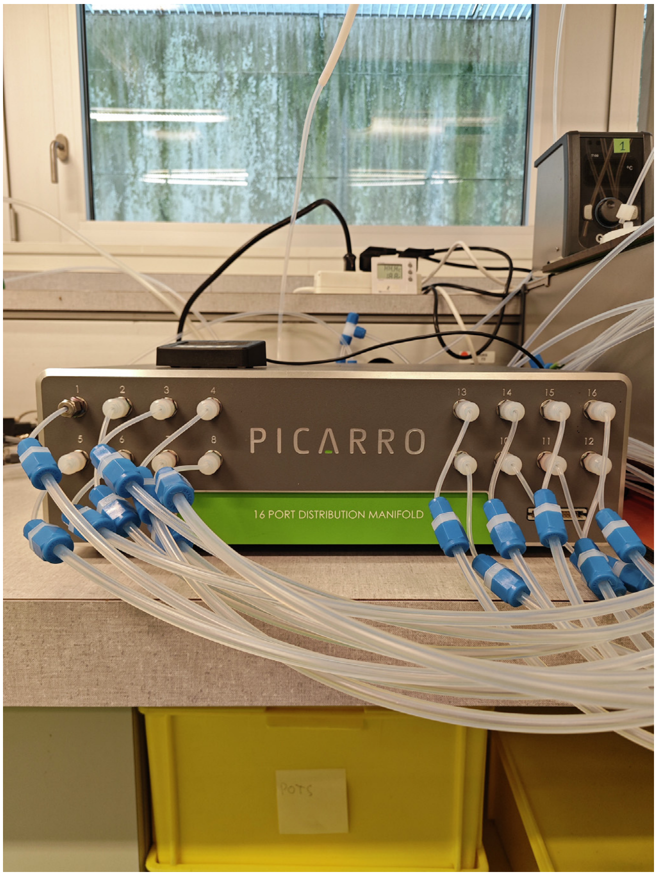

Fig. 2 (*continued*)

Fig. 2 (*continued*)

under the conditions described, all the replicates analysed remained within the CRDS detection range (0–50 ppm) for the entire 168.75-h measurement period. One of the main advantages of using the dynamic flux multichamber system described is the minimal time required from the operator to prepare the instrument for measurement. Human intervention is required only at the beginning of the measurement period for the necessary sample preparation and setup of the whole system. The most time-consuming step involves the preparation of the slurry mix and replicates, which can take up to a maximum of 2 h (for 15 replicates). Once the replicates are prepared and connected to the system, the desired measurement cycle is then set up, and the CRDS, in conjunction with the multichannel sampler, can automatically manage data collection throughout the experiment's duration.

Although the CRDS can operate independently, a regular check (approximately twice a day) of the correct functioning of the system is required, with the possibility of promptly intervening in case of any malfunction. Also, to avoid condensation in the pipes, which can cause significant bias in NH_3 measurements by dissolving ammonia in water droplets, the room temperature should be controlled to match the water bath temperature. Furthermore, the CRDS can be connected to the internet and remotely monitored via a computer control application. It is also important to ensure a sufficient synthetic air supply. In our case, we used a 600-L container (200 bar nominal), which is sufficient for more than a week's measurement. Alternatively, a compressor could also be used with the precaution of subtracting the ambient NH_3 concentration from the slurry NH_3 concentration.

One of the strengths of this method is that the slurry jars and the entire system can be prepared by a single operator. Another major advantage of the system proposed, compared to other labo-

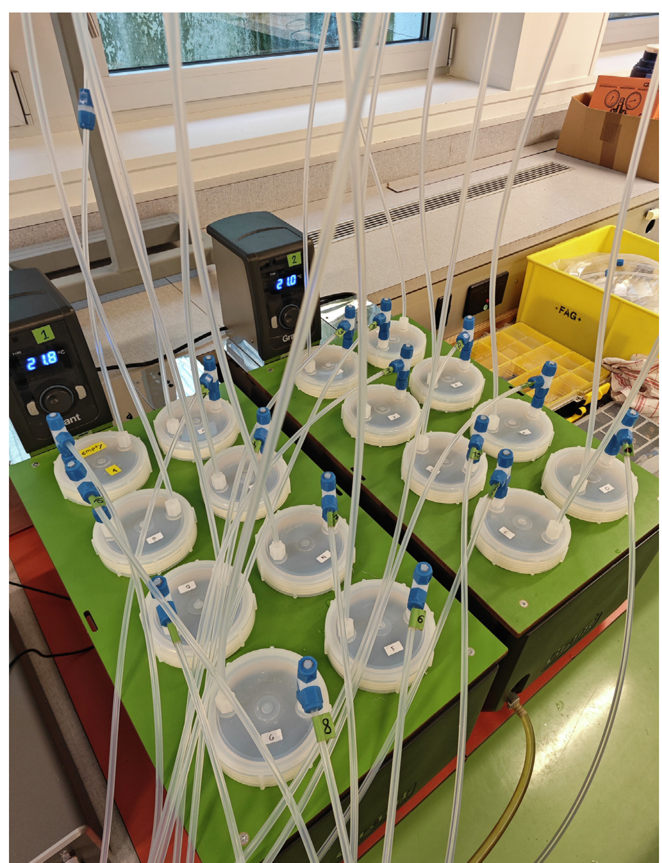

Fig. 2 (*continued*)

Table 1
Area under the curve, peak value, and time to reach the peak of NH_3 in 15 replicates of pig slurry samples.

	Mix 1[1]			Mix 2			Mix 3			Mix 4			Mix 5		
Item	M1a[2]	M1b	M1c	M2a	M2b	M2c	M3a	M3b	M3c	M4a	M4b	M4c	M5a	M5b	M5c
AUC NH_3 (ppm × h)	1 133	1 091	984	1 139	1 057	1 072	1 073	1 017	1 038	1 088	1 051	1 010	1 008	982	1 033
PV NH_3 (ppm)	9.7	9.9	8.6	9.4	9.1	9.5	9.3	8.6	9.1	9.0	8.8	8.2	8.7	8.9	9.2
TTP (h)	69	51	64	63	64	64	65	66	65	66	66	60	62	50	67

Abbreviations: AUC NH_3, area under the curve; PV NH_3, peak value; TTP, time to reach the peak.
[1] Mix 1–5 consisted of 87 g of urine mixed with 87 g of faeces (1:1 w/w) and the diluted with an equal amount of distilled water (1:1 w/w) and blended using a single-blade hand mixer.
[2] M1a–M5c prepared with 100 g of slurry within each mix and splitting the aliquot into three subsamples.

Table 2
Ammonia parameters in pig slurry: mean, SD, and CV calculated between replicate pairs for the area under the curve, peak value, and time to reach the peak.

	Comparison[1]								
	a vs b[2]			a vs c			b vs c		
Item[3]	Mean	SD	CV[4]	Mean	SD	CV	Mean	SD	CV
AUC NH_3 (ppm × h)									
Mix 1	1 112	29.7	2.67	1 058	105.4	9.96	1 038	75.7	7.29
Mix 2	1 098	58.0	5.28	1 106	47.4	4.29	1 064	10.6	1.00
Mix 3	1 045	39.6	3.79	1 056	24.7	2.34	1 028	14.8	1.44
Mix 4	1 070	26.2	2.45	1 049	55.2	5.26	1 030	29.0	2.82
Mix 5	995	18.4	1.85	1 020	17.7	1.74	1 008	36.1	3.58
PV NH_3 (ppm)									
Mix 1	9.8	0.14	1.43	9.1	0.78	8.57	9.2	0.92	10.00
Mix 2	9.2	0.21	2.28	9.4	0.07	0.74	9.3	0.28	3.01
Mix 3	8.9	0.49	5.51	9.2	0.14	1.52	8.8	0.35	3.98
Mix 4	8.9	0.14	1.57	8.6	0.57	6.63	8.5	0.42	4.94
Mix 5	8.8	0.14	1.59	8.9	0.35	3.93	9.1	0.21	2.31
TTP (h)									
Mix 1	60.0	12.73	21.22	66.5	3.54	5.32	57.5	9.19	15.98
Mix 2	63.5	0.71	1.12	63.5	0.71	1.12	64.0	0.00	<0.01
Mix 3	65.5	0.71	1.08	65.0	0.00	<0.01	65.5	0.71	1.08
Mix 4	66.0	0.00	<0.01	63.0	4.24	6.73	63.0	4.24	6.73
Mix 5	56.0	8.49	15.16	64.5	3.54	5.49	58.5	12.02	20.55

Abbreviations: AUC NH_3, area under the curve; PV NH_3, peak value; TTP, time to reach the peak.
[1] Pair of replicates comparison within the same mix. For Mix 1: M1a vs M1b, M1a vs M1c, M1b vs M1c; For Mix 2: M2a vs M2b, M2a vs M2c, M2b vs M2c; For Mix 3: M3a vs M3b, M3a vs M3c, M3b vs M3c; For Mix 4: M4a vs M4b, M4a vs M4c, M4b vs M4c; For Mix 5: M5a vs M5b, M5a vs M5c, M5b vs M5c.
[2] M1a–M5c were prepared with 100 g of slurry within each mix and splitting the aliquot into three subsamples.
[3] Mix 1 to 5: consisted of 87 g of urine mixed with 87 g of faeces (1:1 w/w) and then diluted with an equal amount of distilled water (1:1 w/w) using a single-blade hand mixer.
[4] CV expressed in %.

ratory methods used to measure NH_3 concentration, such as acid traps, which allow only a cumulative NH_3 measurement (Misselbrook et al., 2005a; Antezana et al., 2016), is the possibility to obtain information not only on cumulative NH_3 but also on the volatilisation course over time. The proposed dynamic flux multichamber system also allows for an easy and extensive data collection, performed automatically by the CRDS. During the measurement period, data are saved as.DAT files at intervals defined by the operator. Data are always available and easy to extract directly from the CRDS.

Regarding the repeatability of the method, two measurements are considered to be similar when their CV is a ≤ 10% (Abzalov, 2008; Antezana et al., 2016). Thus, the three replicates within the five mixes can all be considered similar to each other for the parameters AUC NH_3 and PV NH_3 concentration but not for TTP, for which four pairs out of 15 showed a CV > 10%, one reaching a maximum of 21.22%. However, this was not the case when considering Mix 1, Mix 2, Mix 3, Mix 4 and Mix 5. All comparisons showed CVs < 10% for the three parameters. Therefore, retrieving different portions of faeces from the same sample to prepare different mixes resulted only in small variations among the mixes. Other laboratory and field methods for measuring NH_3 emissions from animal slurry have observed CVs between replicates ranging from 7 to 21% (Misselbrook et al., 2005a; Antezana et al., 2016; Pedersen et al., 2020). Antezana et al. (2016), using acid wet traps, proposed a maximum CV of 10% as an acceptable threshold for precision in measuring NH_3 emissions (mg/kg of slurry) between pig slurry replicates. In our study, the CVs for AUC NH_3 and PV NH_3 were below this threshold, supporting the repeatability of the measurements and validating the proposed method. It is interesting to note that when considering the AUC NH_3, all the slurry mixes and slurry replicates depicted a similar NH_3 emission pattern over the measurement period (Fig. 3 and Fig. 4).

Except for the parameter TTP, the differences among replicates were small, which leads the author to conclude that the dynamic flux multichamber system presented in this paper can be regarded as a reliable laboratory-controlled NH_3 measurement method for pig slurry. The authors think that the system can be used as a tool for evaluating the effectiveness of various NH_3

Table 3
Area under the curve, peak value, and time to reach the peak of NH_3 of five pig slurry mixes.

Item[1]	Mean	SD
AUC NH_3 (ppm × h)		
Mix 1	1 069	76.8
Mix 2	1 089	43.7
Mix 3	1 043	28.3
Mix 4	1 050	39.0
Mix 5	1 008	25.0
PV NH_3 (ppm)		
Mix 1	9.4	0.70
Mix 2	9.3	0.21
Mix 3	9.0	0.36
Mix 4	8.7	0.42
Mix 5	8.9	0.25
TTP (h)		
Mix 1	61.3	9.29
Mix 2	63.7	0.58
Mix 3	65.3	0.58
Mix 4	64.0	3.46
Mix 5	59.7	8.74

Abbreviations: AUC NH_3, area under the curve; PV NH_3, peak value; TTP, time to reach the peak.
[1] Mix 1 to 5: consisted of 87 g of urine mixed with 87 g of faeces (1:1 w/w) and then diluted with an equal amount of distilled water (1:1 w/w) using a single-blade hand mixer.

mitigation strategies for pig slurry, such as the effects of low-protein diets, feed additives, and manure treatments. As mentioned in the introduction, the system has its limitations, as various effects affecting NH_3 emissions are not considered. For instance, the dilution used in this method prevents crust formation, which can act as a natural barrier against NH_3 volatilisation (Misselbrook et al., 2005b). Consequently, this protocol may not capture the full potential emission reduction effects of a feeding strategy that promotes slurry crust formation. Moreover, the dilution used for the slurry does not represent the real on-farm situation, but was only used to standardise the method. We would like to emphasise once again that the proposed system is not intended to replace on-farm measurements, but to be a complementary approach. Therefore, the results should be interpreted with caution as an indication of potential NH_3 emission.

Additional applications

The following study considered only the measurement of the NH_3 concentration, given that the replicates were kept under identical conditions (same air flow). If of interest, starting from the concentrations, the emissions can be calculated for each sample by mass balance as:

$$F = \frac{q\,x\,(C_o - C_i)}{A}$$

where F (mg/(min × cm^2)) is the emissions flux, q (L/min) is the airflow through the jar, C_o (mg/cm^3) is the concentration of the air exiting the jar, C_i (mg/cm^3) is the concentration of the air entering the jar, and A (cm^2) is the area emitting the emissions, namely the slurry surface in the jar. This could be of interest, for example, in quantifying ammonia nitrogen losses during a predefined period under consideration.

With the same principle, other gas concentrations (e.g. methane, carbon dioxide, nitrous oxide, and volatile organic compounds) can be measured using other gas concentration analysers.

Conclusion

The proposed laboratory method for measuring NH_3 concentration in pig slurry using a dynamic flux multichamber system provides a standardised and repeatable approach, ensuring consistent experimental conditions across all replicates. The variation within replicates and mix pairs, as indicated by the CVs, remained in an acceptable range. Based on the results, we conclude that two replicates and one mix are sufficient for reliable NH_3 concentration measurement in pig slurry when analysed under the conditions presented in this study.

Peer Review Summary

Peer Review Summary for this article (https://doi.org/10.1016/j.anopes.2025.100111) can be found at the foot of the online page, in Appendix A.

Table 4
Ammonia parameters in pig slurry: mean, SD, and CV calculated between mixes for the area under the curve, peak value, and time to reach the peak.

	AUC NH_3 (ppm × h)			PV NH_3 (ppm)			TTP (h)		
Item[1]	Mean	SD	CV[2]	Mean	SD	CV	Mean	SD	CV
Mix 1 vs Mix 2	1 079	14.1	1.31	9.4	0.07	0.74	62.5	1.70	2.72
Mix 1 vs Mix 3	1 056	18.4	1.74	9.2	0.28	3.04	63.3	2.83	4.47
Mix 1 vs Mix 4	1 060	13.4	1.26	9.1	0.49	5.38	62.6	1.91	3.05
Mix 1 vs Mix 5	1 038	43.1	4.15	9.2	0.35	3.80	60.5	1.13	1.87
Mix 2 vs Mix 3	1 066	32.5	3.05	9.2	0.21	2.28	64.5	1.13	1.75
Mix 2 vs Mix 4	1 070	27.6	2.58	9.0	0.42	4.67	63.9	0.21	0.33
Mix 2 vs Mix 5	1 048	57.3	5.47	9.1	0.28	3.08	61.7	2.83	4.59
Mix 3 vs Mix 4	1 046	4.9	0.47	8.8	0.21	2.39	64.7	0.92	1.42
Mix 3 vs Mix 5	1 026	24.7	2.41	8.9	0.07	0.79	62.5	3.96	6.34
Mix 4 vs Mix 5	1 029	29.7	2.89	8.8	0.14	1.59	61.9	3.04	4.91

Abbreviations: AUC NH_3, area under the curve; PV NH_3, peak value; TTP, time to reach the peak.
[1] Mix 1 to 5: consisted of 87 g of urine mixed with 87 g of faeces (1:1 w/w) and then diluted with an equal amount of distilled water (1:1 w/w) using a single-blade hand mixer.
[2] CV expressed in %.

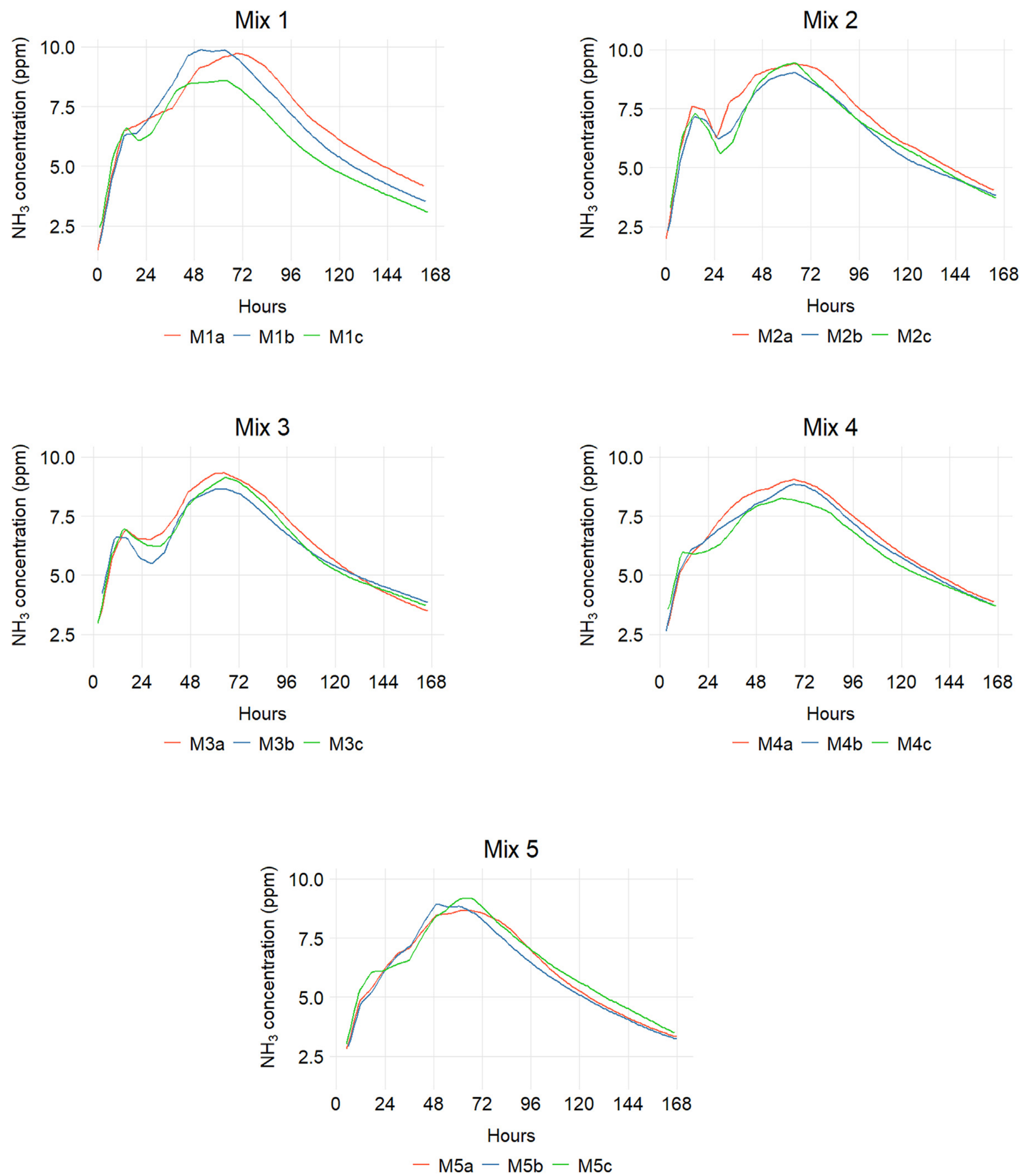

Fig. 3. Ammonia concentration (ppm) in the analysed pig slurry replicates over the 168.75-h measurement period separated by slurry mix.

Ethics approval

This experiment was conducted according to the Swiss Guidelines for Animal Welfare, and the Swiss Cantonal Committee for Animal Care and Use, which approved all procedures involving animals (approval number 2023–43-FR).

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) did not use any AI and AI-assisted technologies.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Giuseppe Bee reports that financial support was provided by Horizon 2020 Research and Innovation Programme under grant

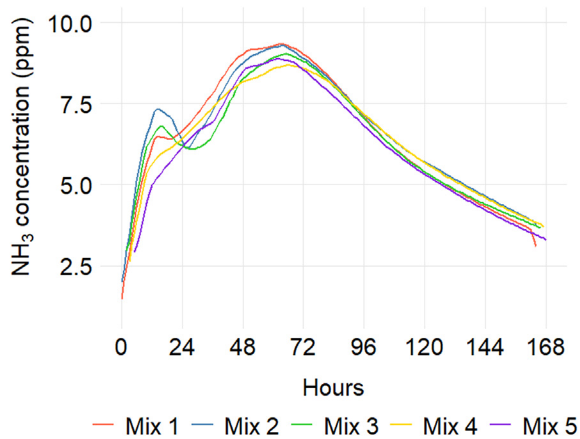

Fig. 4. Ammonia concentration (ppm) in the analysed pig slurry mixes over the 168.75-h measurement period.

agreement No. 101059609. None, if there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors thank the staff of the Agroscope Posieux piggery for the daily care of the animal from which the sample analysed in this study was collected and the staff of the Laboratory for Air Pollution/Environmental Technology of Empa, Duebendorf, Switzerland for the calibration of the CRDS.

Financial support statement

This study is part of the Re-Livestock project and has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101059609.

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