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Highlights

- NH_3 concentrations were measured by INNOVA in a semi-open dairy barn;
- The number of repetitions for each sampling location were assessed;
- The first repetition should be discarded to reduce the variability due to the changing of SL;
- The second or the third repetitions have the lowest variability;
- Up to four repetitions are recommended to avoid measurement change.

Research Paper

Measuring ammonia concentrations by an infrared photo-acoustic multi-gas analyser in an open dairy barn: repetitions planning strategy

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Abstract

The infrared photoacoustic spectroscopy is a common gas sensing technique used for research activities to perform continuous measurement of gas concentrations. Few research works have investigated how to collect data and obtain reliable measurements in open and semi-open dairy houses for gas concentration estimation.

In the present study, measurements of ammonia (NH_3) concentrations were carried out in a semi-open free-stall dairy barn by using a commercial photo-acoustic spectroscopy system (INNOVA by LumaSense Technologies A/S, Denmark), widely used for scientific purposes. Several repetitions for each sampling location (SLs) were investigated in in-field conditions to study the variability of the measurement in each repetition. Based on acquired data, one-way analyses of variance (ANOVA) were carried out for different groups of data. The achieved results showed that the measurement strategy depended on the number of repetitions with effect on the variability of each measurement. In detail, the number of repetitions performed had a significant influence on data collection ($P<0.001$). From the outcomes of the research, it is recommended to: perform three repetitions, or at most, four repetitions for each SLs; exclude the first repetition from the data analyses because it reduces measurement variability; consider the mean value of the second and third repetitions as the NH_3 concentration value determined at each SL; up to four repetitions (that would take a five-minutes acquisition) are recommended because measurement changed in time when a higher number of repetitions were carried out. The measurement design should be planned based on the number of repetitions and the number of SLs in order to perform more than one SL measurement cycle within an hour. Since the measurement cycles are strictly related to the number of SLs in the barn, they depend on the barn typology and dimensions.

The application of a specific measurement strategy is valuable to obtain reliable data that could be used in the research activities focused on estimation of gas concentrations for monitoring air quality, improving animal welfare, assessing mitigation strategies, or estimating emissions in open and semi-open free-stall dairy barns.

Keywords: ammonia, gas concentrations, repetitions, measurement strategy, open-sided dairy barn

1. Introduction

In the last decades, the scientific community has been mainly focused on the estimation of gas emissions from the livestock sector due to environmental concerns. It is widely acknowledged, in fact, that agriculture is responsible for the 94% of the of ammonia (NH_3) production within Europe (Tullo et al. 2019). In detail, the dairy sector is a relevant category that produces NH_3 emissions at farm level with negative effects on both human health and ecosystems (de Vries, 2021). Since the estimation of NH_3 emissions plays a relevant role in the identification of mitigation strategies, the application of precise measurement techniques and instruments can improve the quality of data for both estimation purposes and monitoring of the pollutants in the barn environment.

Among the main measurement techniques (Hassouna and Heglin, 2016), the infrared photoacoustic spectroscopy is used for research activities to perform continuous concentrations measurement of one or more gases. The measurement principle is based on the analysis of an air sample in a measurement chamber, equipped with optical filters. First of all, the sample is sucked into the measurement chamber, then sealed by valves. Secondly, an intermittent infrared source passes through a chopper and an optical filter into the chamber and is irradiated onto gas sample. Based on the radiation energy absorbed by the gas in proportion to the concentration, the gas sample emits acoustic waves that are detected by microphones and the signal is, finally, post processed and the gas concentration can be estimated.

In the literature many authors (Ngwabie et al. 2011; Bijerg et al., 2012; Hassouna et al., 2013; Ngwabie et al. 2014; Saha et al., 2014a; Hempel et al., 2016; Schmithausen et al. 2018, D'Urso and Arcidiacono, 2021) have monitored gas concentrations from different livestock housing by using INNOVA multi-gas analysers (LumaSense Technologies A/S, Denmark). This device is based on the infrared photoacoustic spectroscopy principle, and it can measure up to five gases (e.g., NH_3, methane, carbon dioxide, nitrous oxide) in a sampling point. When the INNOVA is combined with a multiplexer, it allows acquiring gas concentrations in different points. However, INNOVA is not able to measure the gases simultaneously in all the sampling points, but it measures simultaneously all the gases in a specific sampling point accordingly to a continuous sequence. In some studies, INNOVA was applied in both in-field conditions (Saha et al. 2014b) and a scale model building (Shen et al. 2012) to acquire carbon dioxide concentrations in many sampling points in order to assess the ventilation rate. Since this kind of multi-gas analysers provides precise and reliable measurements (Zhuang et al., 2020), the INNOVA is also used in research studies as a reference method to assess the performance of other devices (Li et al., 2015; Mendes et al., 2015; Schmithausen et al. 2016; Wang et al., 2016). Moreover, this device was recently assessed in the study of von Jasmund et al. (2022) by using a gas calibration unit.

During the measurement with INNOVA, non-target gas can produce an interference. According to Hassouna et al., (2013) non-compensated interferences between gases induce an overestimation of gas concentrations and a cascade effect induces underestimation. A relevant role for obtaining reliable measurements is carried out by the instrument (e.g., precision) and the design of the measurement campaign (e.g., sampling frequency, number of measurement points, sampling positions, and time duration of the measurement). Moreover, the gas concentrations from animal housing are influenced by the spatial and temporal variability of the measure due to the environmental conditions and barn management (Saha et al., 2013, Rong et al. 2014, Mendes et al. 2017, D'Urso et al., 2021a) thus it is unlikely that a uniform distribution of a gas within the building occurs. According to Calvet et al. (2013), the execution of measurement repetitions in time can reduce random errors that derive from unpredictable temporal variations of the measured values.

Based on the literature, few studies have investigated the number of repetitions to be performed by an INNOVA device. In detail, the study of Brehme (2003) defined specific information about experiment design based on the analyses carried out in a duck farm during 20 months of observation. The results reported that the adequate number of repetitions is ten. Moreover, the author suggested performing three repetitions and rejecting the first and the second values for each sampling point. This conclusion is based on the fact that although excluding the first and the second repetition would produce a data loss of 66%, the third repetition will have the 33% of the realistic value. However, this study showed neither error analysis nor statistical evidence. Another study was carried out by Rom & Zhang (2010) in laboratory conditions; they recommended to measure gas concentrations from a minimum of 12.5 to a maximum of 25 minutes on each position. The authors proposed some suggestions regarding the design of the measurement set up and measurement strategies, however the results were not verified in in-field conditions. In the study of Ngwabie et al. (2009), similar recommendations were applied by sequentially measuring at different indoor sampling locations before switching to outdoor ones, although it was not specified whether replicates for each location were performed. Wu et al. (2012) measured six times at each sampling point with a sampling frequency of less than one minute. The NH_3 concentration at each sampling point was determined by the average of the last three repeated values in the measurement, while other gas concentrations were calculated as the mean of all the six repeated values. In the study of Hassouna et al. (2013), the gas concentrations were acquired in a poultry building every two minutes for 20 minutes before switching to the next sampling location. A sampling frequency of 1 minute was also applied by De Vogeeler et al. (2017) in a naturally ventilated animal mock-up building. In this study, gas concentrations were continuously measured in five sampling points and two measurements were carried out for each sampling point before measuring the next point. In different studies, no replicates for each sampling point were carried out. In detail, Zhang et al. (2005) measured gas concentrations at six sampling points with a sampling frequency of 20 minutes, whereas D'Urso et al. (2021b) used a sampling frequency of 15 min for each sampling point. Other studies (Saha et al., 2013; Hempel et al., 2016) measured gas concentrations at twelve sampling points in a naturally ventilated dairy barn. The INNOVA required 1 minute for each sampling point and, thus, the sequence of the 12 sampling points was completed in about 12 minutes. In another study by Fiedler et al. (2014), gas concentrations were continuous acquired in many sampling points according to a continuous sequence, yet no further information on sampling frequency or number of replicates was provided. Since the measurement of gas concentrations is useful for the emission estimation, the recent VERA Test Protocol (2018) provides a guideline on the measurement strategy (i.e., measuring period, measurement locations, and measuring methods) for emission estimation. However, specific recommendation on the set-up of number of replicates to acquire gas concentrations was not specifically provided for the measurement device.

Based on the literature, the research studies have applied different methods to acquire gas concentrations and most of them did not set the INNOVA device in order to make repetitions for each sampling point. Therefore, the aim of this research study was to evaluate the optimal number of repetitions for gas concentrations measured by the INNOVA device under in-field conditions. The objective was to identify the optimal number through statistical analyses in order to provide specific criteria for the design of the measurement campaign. In detail, several repetitions were assessed by studying the variability associated to a specific measurement. Specifically, the number of repetitions needed to minimise the variability were investigated.

2. Materials and methods

2.1. Site description and gas concentration measurements

Measurements were carried out in a cubicle free-stall dairy barn located in South Italy (37°01'N, 14°32'E) within the province of Ragusa. The building is about 55.50 m long and 20.80 m wide with three sides completely open (Figure 1). The roof is symmetric with a central ridge vent having a 7m ridge height and a 4m eave height. Different areas compose the indoor environment of the barn: the farmer office, boxes for calves, and cow's functional areas including the resting area with 64 head-to-head cubicles organised in three pens. In each pen the cubicles are organised in two rows built of concrete kerbs and covered with sand (Figure 2).

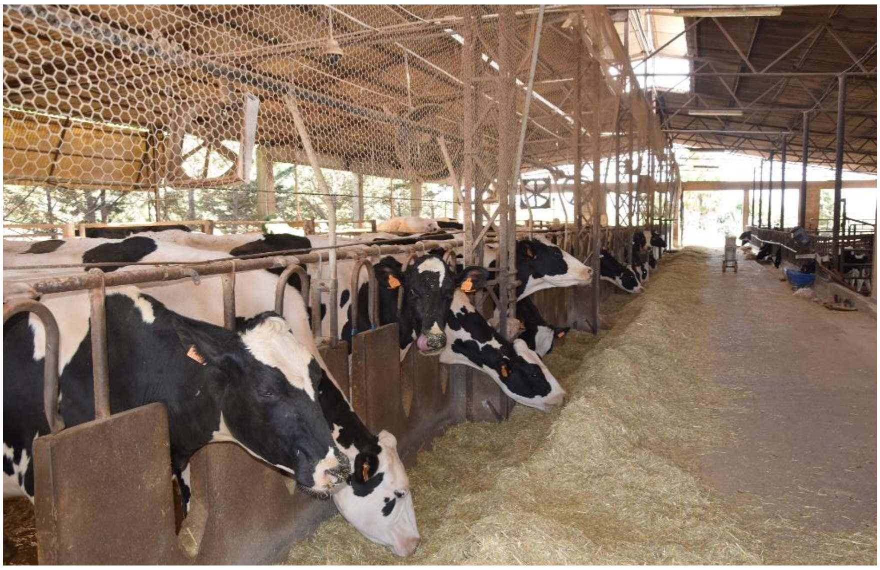

Figure 1. View of the barn with the open-sided walls.

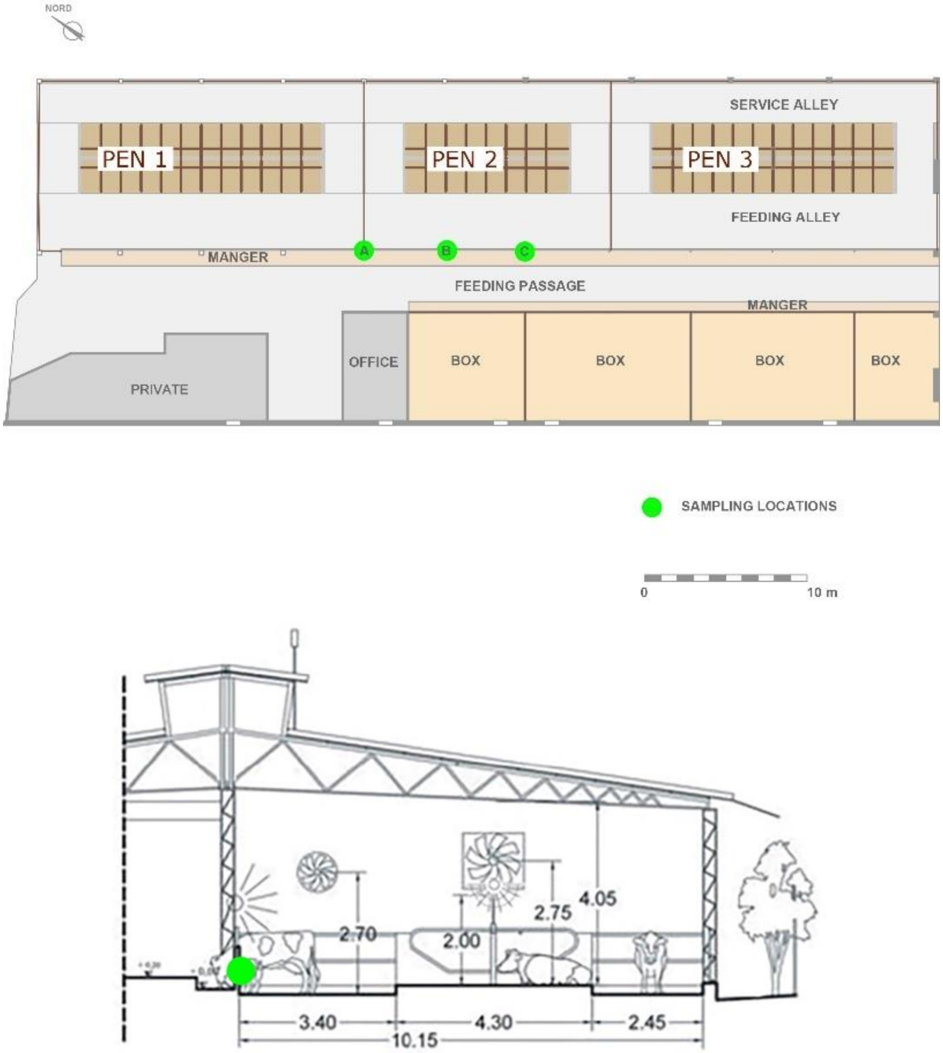

Figure 2. Plan and section of the barn with localisation of sampling locations.

NH_3 concentrations were continuously measured by an INNOVA photo-acoustic analyser, which was calibrated by the manufacturer before the beginning of the measurement campaign in 2018. The INNOVA analyser was composed of a Multigas Monitor mod 1412i and a multipoint sampler 1409/12 (Lumasense Technology A/S, Denmark) with 12 inlet channels. The sampler system is made of AISI-316 stainless steel and PTFE (poly-tetrafluoroethylene) tubing to minimise adsorption of samples. An air-filter was attached to the end of each sampling tube to keep the 1409 free of particles. The declared resolution of the instrument by the manufacturer is equal to 1 % of the measured value and its accuracy is lower than the 3 % of the measured value under standard condition with T° = 20°C and RH = 60%.

Data were acquired from 19/06/2018 to 30/06/2018 with an indoor and outdoor air temperature of 27.6 ± 5.1°C and 26.5 ± 4.9°C, respectively, and indoor and outdoor air velocity of 0.73 ± 0.46 m s^{-1} and 1.29 ± 0.68 m s^{-1}. During the experiment, gas concentrations of NH_3 were continuously acquired at three sampling locations (i.e., SL_A, SL_B, and SL_C) located in the central pen of the barn (Figure 2). The SLs were installed at 20 cm from the barn floor in the animal occupied zone (AOZ) according to the findings of Arcidiacono et al. (2015). In detail, the localisation in the central area of the barn allows obtaining gas concentrations values that are not significantly different (D'Urso et al., 2021a). Moreover, the sampling points were located at 20 cm from the floor to reduce the influence of the indoor conditions related to the open envelope, as it was found in the study by D'Urso et al. (2022).

The measurement cycle was composed by the sequence of the SL_A, SL_B, and SL_C. INNOVA device was set to perform continuously ten repetitions for each SL before switching to the next SL. For each repetition, the INNOVA measures the gas concentrations in a specific SL. In the present research study, the INNOVA required about 1 minute 15 seconds for each repetition, about 11 minutes and 15 seconds for each SL (i.e., time required to perform ten repetitions) and less than one hour for a measurement cycle.

2.2. Processing datasets and statistical analyses

Data collected during the observation periods were organised into different datasets for each SLs by using Excel© software.

The variability related to a specific repetition $\varepsilon_i(\%)$ was computed by using the following relation:

$$\varepsilon_i(\%) = \frac{x_{GS} - x_i}{x_{GS}} * 100 \qquad \text{with i} = 1,..,10$$

where x_{GS} was the gas concentration value of repetition used as benchmark and x_i was the value of gas concentrations in the *i-th* repetition. Different values of the benchmark were assessed in this study based on specific recommendation found in the literature. In detail, based on the study of Brehme (2003), the tenth repetition was considered as x_{GS}. Moreover, according to the author, the third repetition was considered as x_{GS} based on the balance between the number of sampling locations when more repetitions are carried out and the data loss. In this study, the first and the second repetitions were also considered as x_{GS} to quantify the error in considering those repetitions. With regard to the repetition time length, Rom and Zhang (2010) recommended to measure gas concentrations for at least 12.5 minutes. Since the INNOVA requires about 11 minutes and 15 seconds to execute ten repetitions in each SLs, the present study investigated both the tenth repetition and the mean values of the ten repetitions as x_{GS}. In addition, also other repetitions or repetition means were tested as benchmark to investigate the variability of the measurement.

Datasets of positive and negative $\varepsilon_i(\%)$ associated to the i-th repetition were organised in a database for each SLs and the considered benchmark. Then, the one-way analysis of variance (ANOVA) was applied in order to statistically determine whether significant differences occurred between the positive (or negative) variability associated to a specific repetition in a SL. The level of significance was a P value (p) lower than 0.05. If the test was significant ($p < 0.05$), the applied post hoc test was the Tukey test which identified differences between groups of positive (or negative) variability for a specific repetition in a SL.

3. Results and discussion

3.1. Variability related to the repetition chosen as benchmark

The results of the one-way ANOVA applied for each benchmark under analysis showed p-values lower than 0.05 for each considered SL. Based on the post hoc analysis (Table 1), the positive (or negative) variability showed significant differences related to the i-th considered repetition. Since the results of this study were confirmed for all the SLs, only the values related to the SLB were reported in the following of the text.

In detail, when the benchmark in SLB was the first repetition, it was found that the ε_2 differs from the others, except for ε_3. However, the negative ε_2 value (i.e., -4.73) obtained by fixing the first repetition as the benchmark was greater compared to the negative ε_2 (i.e., -3.12) when the third repetition was considered the benchmark. Therefore, the first repetition cannot be considered as a benchmark. Moreover, the study of the frequency of the variability showed an underestimation of the measurement in the 55.8% - 59.5% of the cases rather than an overestimation (40.5-44.2%) when the first repetition was considered as the benchmark.

When the benchmark was the second repetition, the ε_3 differed from the variability associated to all those repetitions from the 5th to the 10th, except for ε_1 and ε_4 for positive variability and for ε_4 for negative variability.

When the third repetition was considered as the benchmark, positive and negative ε_1 were higher than ε_2 and ε_4. Therefore, the first repetition overestimated or underestimated the value acquired in the third repetition with a variability higher than ε_2 and ε_4. This result highlights that it is not equivalent to consider the first or the third repetition whereas the second, third or fourth repetition are statistically equivalent. In addition, also the fifth repetition could be considered from the statistical point of view, though accepting a higher variability.

When the considered benchmark was the mean value of gas concentration of the second and the third repetitions, the ε_2 and ε_3 were significantly different from the variability in other repetitions with values lower than ±2%, except for ε_4 (for positive variability).

In the Tukey test, carried out by considering the fifth repetition as benchmark, ε_3 was higher than ε_4 and ε_6 with a difference of about 1-1.5%. Based on the results, the fifth repetition overestimated or underestimated the value of the third repetition because the measurement value was changing over time, influenced by different factors. Therefore, considering the fifth or third repetition as benchmark is not equivalent, whereas the fourth or the sixth repetitions are statistically equivalent when the benchmark is the fifth repetition.

When the benchmark was the tenth repetition, the error ε_1 ε_3 , and ε_5 ranged from about 7% to about 14% for both positive and negative values of variability. In detail, the nineth repetition highly overestimated or underestimated the measured values compared to the fifth, the third and the first repetitions. Therefore, taking the nineth or the fifth repetitions was not equivalent, whereas the ninth repetition was equivalent to the eighth repetition. This result confirmed that the measurement value was changing over time. In the last analysis, the mean value of the tenth repetition considered as benchmark produced the lowest variability in the fifth repetition and high variability in the first, second and third repetitions.

The outcomes of SL_B were verified in the other SL_A and SL_C. Based on the statistical analyses, there was not a relevant difference among the results in SL_B, SL_A and SL_C. The results confirmed that: the first repetition should not be considered; a high number of repetitions increases the variability due to the changing of gas concentration in time during in-field experiments.

Table 1. Results of the post-hoc Tuckey test for the variability associated to the number of repetitions ε_i(%) for SLB.

XGS	**First repetition**			**Second repetition**		
	Rep.	**Mean**	**Grouping**	**Rep.**	**Mean**	**Grouping**
positive	10	11.11	A	10	9.47	A
	9	10.45	A B	9	9.00	A
	8	10.02	A B	8	8.42	A B
	7	9.15	A B	7	8.28	A B
	6	8.50	B C	6	6.72	B C

	5	7.91	B C	5	5.83	C D
	4	6.58	C D	4	4.50	D E
	3	5.20	D E	1	4.39	D E
	2	3.71	E	3	2.97	E
negative	2	-4.74	A	1	-3.96	A
	3	-7.08	A B	3	-4.01	A
	4	-8.71	B C	4	-6.13	A B
	5	-9.26	B C D	5	-7.10	B C
	6	-10.54	C D E	6	-8.52	C D
	7	-11.78	D E F	7	-9.07	C D E
	8	-12.39	E F	8	-10.36	D E F
	9	-13.45	F	9	-11.16	E F
	10	-13.79	F	10	-11.55	F

XGS	**Third repetition**			**Mean value of the second and third repetitions**		
	Rep.	**Mean**	**Grouping**	**Rep.**	**Mean**	**Grouping**
positive	10	7.98	A	10	8.73	A
	9	7.63	A B	9	8.20	A B
	8	7.01	A B	8	7.47	A B C
	1	6.33	B C	7	7.03	B C
	7	6.31	B C	6	5.95	C D
	6	5.31	C D	1	5.14	D E
	5	4.53	D	5	5.05	D E
	2	3.76	D E	4	3.56	E F
	4	2.82	E	2	1.94	F G
				3	1.52	G
negative	2	-3.12	A	2	-1.52	A
	4	-3.85	A B	3	-1.94	A
	5	-4.86	A B C	4	-4.65	B
	1	-5.74	B C D	1	-4.70	B
	6	-6.51	C D	5	-5.71	B C
	7	-7.61	D E	6	-7.18	C D
	8	-9.04	E F	7	-8.23	D E
	9	-9.95	F	8	-9.59	E F
	10	-10.51	F	9	-10.38	F
				10	-10.75	F

	Fifth repetition			**Tenth repetition**			**Mean of the ten repetitions**		
XGS	**Rep.**	**Mean**	**Grouping**	**Rep.**	**Mean**	**Grouping**	**Rep.**	**Mean**	**Grouping**
positive	1	7.98	A	1	11.35	A	1	7.30	A
	10	6.87	A B	2	9.77	A B	10	5.49	B
	2	6.35	B C	3	8.99	B C	2	5.41	B C
	9	6.30	B C	4	8.30	B C	9	4.86	B C D
	8	5.13	C D	5	7.58	C D	3	4.10	C D E
	3	4.46	D E	6	6.19	D E	8	4.06	D E
	7	4.35	D E	7	5.54	E	7	3.57	D E
	4	3.16	E F	8	4.57	E F	4	3.33	E
	6	2.76	F	9	3.02	F	5	3.18	E
							6	2.88	E
negative	4	-2.98	A	9	-2.90	A	5	-3.03	A
	6	-3.52	A B	8	-4.52	A B	6	-3.25	A
	3	-4.88	A B C	7	-5.76	B C	4	-3.32	A B
	7	-5.18	B C	6	-7.27	B C D	7	-3.79	A B
	2	-6.47	C D	5	-7.85	C D	3	-3.86	A B
	8	-6.85	C D E	4	-8.33	C D	8	-4.73	B C
	9	-7.98	D E F	3	-9.42	D E	2	-5.57	C D
	10	-8.77	E F	2	-11.52	E F	9	-5.67	C D
	1	-9.18	F	1	-14.05	F	10	-6.44	D

1	-7.94	E

3.2. Measurement strategy

Based on the investigation carried out in these experiments, the number of repetitions for each SL had a significant influence on data collection. For this reason, the measurement design should be organised with some repetitions for each SLs. The results recommend excluding the first and the tenth repetitions because their value ε_i had the highest variation from about -14% to the 11%. Excluding the first repetition is in line with what suggested by Brehme (2003) that stated that the first and the second repetitions were less realistic than the third repetition. Moreover, this author reported that the best number of repetitions were ten. In the present work, the results did not corroborate this statement. In fact, besides the highest variability ε_i when the benchmark was the tenth repetition, the ten repetitions had the highest variability $\varepsilon_{10}$when the benchmark was the first, the second and the third repetitions. When the benchmark was the fifth and the mean value of all the ten repetitions, the errors ε_9 and ε_{10} had highest value and were not significantly different from ε_1. Therefore, increasing the number of the repetitions, in order to have representative data for uniform conditions, does not ensure a higher reliability of the concentrations because the time required by the instrument to perform the measurement increases and, at the meantime, the gas concentrations could be modified in the barn environment. In fact, since each repetition required about 1 minute 15 seconds, ten repetitions required about 11 minutes for each SL. During the range of about 11 minutes, the gas concentration was not constant under in-field conditions (Figure 3). In fact, different typologies of the NH_3 trend with a different variation of the curve slope during the time period of the ten repetitions were found in the experiments. This variation could be attributed not only to the random error of the measure (Calvet et al. 2013), but also to other factors that make the analysis much complex. In detail, as it was recently found in the literature (Saha et al., 2014a, Poteko et al., 2019; Zou et al., 2020; D'Urso et al., 2021a; D'Urso and Arcidiacono, 2021; D'Urso et al., 2022), multiple factors influence the measurement of NH_3 concentrations, such as building configurations, measurement locations, size of the openings, climatic conditions, animal behaviour, barn management, and housing design.

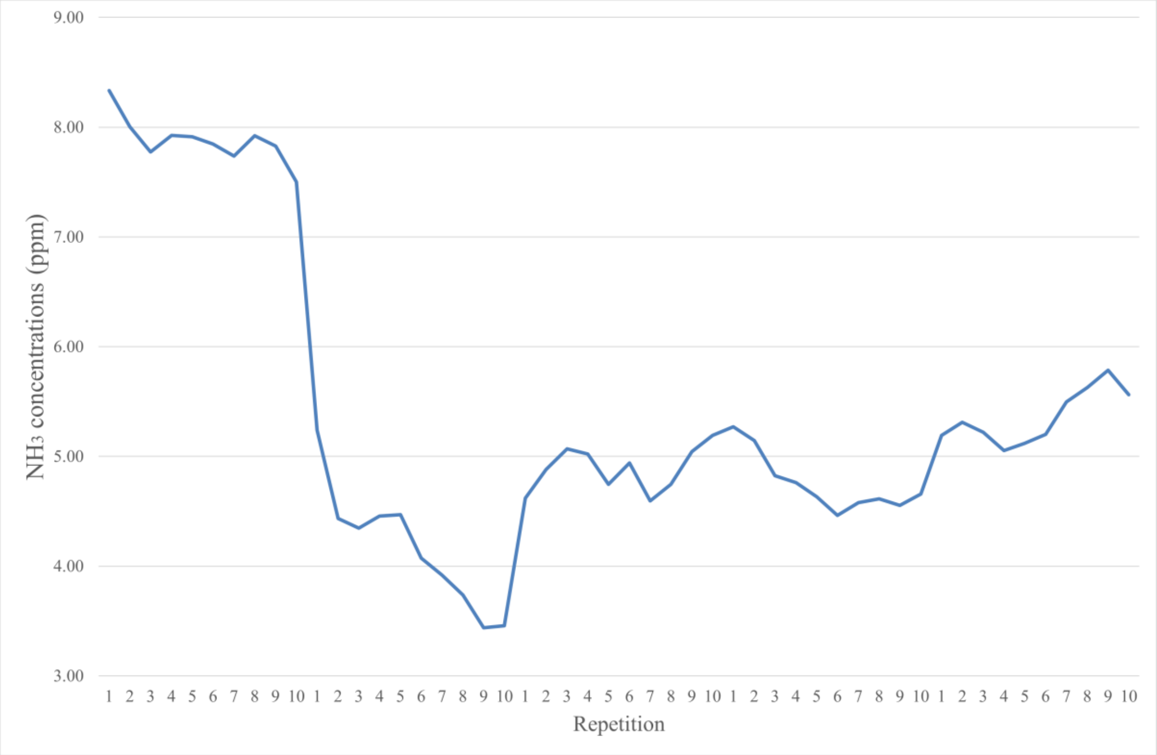

Figure 3. NH_3 concentrations trend during five measurement cycles at SLB with 10 repetitions for each measurement cycle.

For this reason, the NH_3 concentration recorded in the fifth repetition generally overestimated or underestimated the value of the second or third repetition and the number of repetitions should not be more than five. Although Zhang and Rong (2010) found that measuring periods should last from 12.5 to 25 minutes in laboratory conditions, the outcome of this study recommended to reduce the measuring periods under in-field conditions to obtain more precise values of the gas. In the present experiment, ten repetitions for each SLs required about 11 minutes but, starting from the fifth repetitions the values of gas concentrations had a significantly higher variability. Therefore, in this barn typology it is recommended to reduce the number of repetitions and perform three or, at least, four repetitions. In this way, this number of repetitions could increase the precision of the results. In fact, precision is acknowledged as the measurement of how tightly clustered the forecast dispersion is. Based on the results of this study the best solution is to perform three repetitions for each SLs, then exclude the first repetition due to the high variability and, then again, compute the mean value of gas concentrations recorded in the second and in the third repetitions.

By reducing the number of repetitions, a relevant effect is saving time to perform further measurements cycles and obtain more data with a higher frequency. In fact, a measurement cycle with three SLs and ten repetitions required about 34 minutes to the INNOVA and allowed achieving a complete measurement cycle every hour. When the repetitions are five for each SL and the SL are three, the measurement cycle required about 15 minutes thus allowing -the data acquisition data in four measurement cycles within an hour. A measurement cycle at three SLs and with three repetitions will allow performing up to six measurement cycles during an hour. This could have positive effect also in the emission estimation. In fact, in the literature (Saha et al., 2014, Hempel et al. 2016, Janke et al., 2020), the authors generally estimate the emissions using the hourly mean value of gas concentrations when more than one measurement is available. In other cases, when there is not a value of gas concentration for each hour, it was used the interpolation method (Hassouna et al., 2013). A correct planning of the number of repetitions as well as the number of SLs could increase the reliability of the measurement because, besides the number of repetitions for each SLs, a higher number of measurement cycles could be planned in order to obtain more values to determine the hourly mean value of gas concentrations, useful for emission estimation. For this reason, the barn dimension and typology have a great influence on the design of the measurement campaign. Reduced barn plan dimensions allow decreasing the number of SLs and increasing repetitions with a significant improvement of the precision of collected data. Moreover, the correct location of SLs in the barn plan could avoid monitoring those places in the barn that can increase the uncertainty in the emission estimation (König et al., 2018; Janke et al., 2020; D’Urso et al. 2021c)

4. Conclusions

In this study, the concentration of NH_3 was measured in an open naturally ventilated dairy barn during the warm period in the Mediterranean area. The measurement campaign was carried out by using the INNOVA photo-acoustic analyser, and different repetitions were performed for each sampling location (SL). The results of this work highlighted a measurement strategy for acquiring data of gas concentrations with INNOVA in a open barn typology. Based on this research study, it is possible to conclude that increasing in the number of the repetitions does not ensure a higher reliability of the gas concentrations.

A measurement protocol for open or semi-open dairy barn could represent a fundamental step for monitoring air quality, improving animal welfare, assessing mitigation strategies, or estimating emissions. Moreover, the implication of this research study could be helpful in elaborating a potential revision of the next VERA protocol. An improved knowledge is needed related to the vertical position of SLs, the distance from the perimeter (without wall) to the SLs, the influence of climatic factor or barn management in the uncertainty of measurements. Based on the advancement in measuring gas concentrations, the following step is to evaluate the impact of different positions of SLs in the monitoring of gas concentrations in open and semi-open dairy barns. Moreover, the application of a measuring strategy in this barn typology to obtain emission factor has not yet been assessed.

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