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# Comparison of the Three Approaches for Determining Ammonia Emissions in the Intensive Breeding of Fattening Pigs with Respect to the Integrated Pollution Prevention and Control: Case Study for the Czech Republic

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**Abstract:** This study compares three approaches in the monitoring of ammonia ($NH_3$) emissions from intensive breeding of fattening pigs in relation to compliance with the standards arising from the requirements of Integrated Pollution Prevention and Control (IPPC) used in the Czech Republic. The first approach was based on the determination of $NH_3$ emissions calculation by measurement using reduced sampling days focused on the final fattening phase. The second approach was based on the determination of $NH_3$ emissions calculation by measurement respecting the Best Reference Document for Intensive Rearing of Poultry or Pig (BREF IRPP) and relevant best available techniques (BAT) conclusions under Directive 2010/75/EU. The third approach was based on estimation by using emission factors respecting BREF IRPP and Methodological Instruction of the Air Protection Department of the Czech Republic. The results show that the determined emission factors in the Czech Republic may not always reflect the actual production of $NH_3$ emissions even when reduced by the applied BAT. Determination of $NH_3$ emissions calculation by measurement respecting BREF IRPP represents the predominant phases of fattening (refinement) and microclimatic conditions; however, it is time and money-consuming.

**Keywords:** air pollution; IPPC; pig farm; BREF; BAT

## 1. Introduction

The largest source of $NH_3$ emissions is agriculture, including animal husbandry and $NH_3$-based fertilizer applications [1]. Nowadays, animal husbandry is a significant source of $CH_4$, $NO_x$, $CO_2$, and $NH_3$ in agriculture [2]. $NH_3$ release into the atmosphere is caused by the reactions of urease enzyme or microbial activity while consuming unconverted nitrogen originating from high-protein feeds used to fulfill nutritional requirements [3]. Nitrogen-based emissions are probably caused by $NH_3$ ($NH_3$-N) losses from the interconversion of total ammoniacal nitrogen ($NH_3$-N + $NH_4^+$-N) and organic nitrogen, eventually in the case of the aqueous equilibrium of ($NH_3$-N) and ($NH_4^+$-N) [4]. $NH_3$ emissions have a negative influence on the environment. After deposing the ecosystems, excess nitrogen, including $NH_3$, could cause nutrient imbalances and eutrophication. $NH_3$ also plays a primary role in the deterioration of atmospheric visibility as nitrogen is deposited in the atmosphere [5]. $NH_3$, as a prevalent harmful gas in the atmosphere with an amount of approximately 55 Tg-N, reacts chemically with other gases such as $SO_2$ and neutralizes the hydrogen ion. It remains in the atmosphere for a short time, a few hours to a day, and it mostly returns to the ground, but in an altered form [6]. Humans and land animals are at low risk of contracting illnesses due to ammonium consumption [7].

However, an increase in $NH_3$ concentration contributes to particulate matter ($PM_{2.5}$) formation in the atmosphere. The contribution of $NH_3$ to atmospheric aerosols affects human health, which can increase the likelihood of hospitalization [8]. As a result of exposure to fine $PM_{2.5}$, air pollution is one of the leading causes of damage to human health in Europe with an estimate of about 380,000 premature deaths per year in the European Union (EU) [9]. Furthermore, $NH_3$ emissions are expected to increase [10], which gives cause for concern. In the EU, the focus lies on pig and poultry housing facilities, which contribute to $NH_3$ emissions [11]. According to [12], pig farming is globally responsible for about 15% of emissions associated with livestock breeding. Worldwide pig consumption had been expected to increase by 75% between 2000 and 2020 [13].

Furthermore, [14] stated that pig production is responsible for nearly 25% of livestock $NH_3$ emissions. If all assessments of the environmental impacts of the areas of $NH_3$ emission are handled in a new area-based regulation, it would be possible to issue an environmental permit where the production is kept in the existing pig buildings even with increased pig production [15]. Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions (integrated pollution prevention and control), which sets out rules for reducing emissions to air, water, and land and preventing waste, is intended to help reduce the production of $NH_3$ and other harmful substances from intensive livestock farming. It also applies to intensive poultry farms with a capacity of more than 40,000, fattening pig farms with a capacity of more than 2000, or sow farms with a capacity of more than 750. These farms must have an integrated operating permit [16]. In order to achieve environmental standards, they use the best available techniques (BAT), which are listed in the Best Reference Document for Intensive Rearing of Poultry or Pig (BREF IRPP) [17]. The implementation of these policies has resulted in an estimated 40–85% reduction in emissions over the last 15 years, depending on the pollutant [18]. Ref. [19] provides in his study an overview of BAT that reduce emissions from livestock production. They divide them according to the areas of application into: emission reduction by modifying the animals' diet (reduction of nitrogen and phosphorus excretion), methods of emission reduction in connection with livestock housing (floor modification, ventilation, air cleaning, removal, and storage of excreta), principles of proper manure storage (covering of storage areas, modification of composition, appropriate placement), and spreading of manure on the soil (technology of spreading, time of application from spreading).

Monitoring of $NH_3$ emissions in the EU is currently incomplete but should continue, especially for pig breeding. All the essential factors for building structures and management policies are linked to animal well-being, indoor air quality, and environmental pollution [20]. The magnitude of emissions and factors influencing emissions from pig farming can only be studied if proper measurement techniques are available [21]. Techniques for monitoring the production of $NH_3$ emissions according to BAT 25.C [22] include:

- *Estimation using mass balance by excreted and total nitrogen (or ammoniacal).* Estimation by excreted nitrogen or total ammoniacal nitrogen and volatilization coefficients for each stage of manure handling (housing, storage, landspreading). The general equations for the calculation are:

$$E_{housing} = N_{excreted} \cdot VC_{housing}, \tag{1}$$

$$E_{storage} = N_{storage} \cdot VC_{storage}, \tag{2}$$

$$E_{spreading} = N_{spreading} \cdot VC_{spreading}, \tag{3}$$

where $E$ is the annual $NH_3$ emission, $N$ is the total annual excreted nitrogen or ammoniacal nitrogen, and $VC$ is the volatilization coefficient, which is specified in international or national protocols for each EU country [22].

- *Calculation by measuring the internal $NH_3$ concentration and ventilation performance*. Monitoring should be carried out on at least 6 days divided over one year. Fattening pigs is defined as a farm with a linear increase in emissions per breeding cycle; therefore, the measurement days are evenly distributed over the growing period (50% of the measurements in the first half of the breeding cycle and 50% of the measurements in the second half of the breeding cycle). The daily average is calculated as the mean over all sampling days. One measurement shall be taken over a 24 h period and shall be taken at the air inlet and outlet of the housing (breeding pen). The daily average of $NH_3$ emissions is multiplied by the number of days the housing is occupied to obtain the annual emissions [22,23].
- *Estimation using emission factors*. $NH_3$ emissions are estimated using emission factors determined according to national or international protocols. These are determined on the basis of housing, manure storage, and landspreading [22].

Therefore, this study aimed to compare three approaches for the determination of $NH_3$ emissions from intensive fattening pig farming.

The first approach basically determined $NH_3$ emissions by calculation from measurements of the internal $NH_3$ concentration in the breeding house with reduced sampling days focused on the final fattening phase.

The second approach basically determined $NH_3$ emissions by calculation from measurements of the internal $NH_3$ concentration in the breeding house, strictly BREF IRPP [17] and relevant BAT conclusions under Directive 2010/75/EU [22].

The third approach was determined according to the estimation by emission factors that are valid in the Czech Republic [24] and respect BREF IRPP [17].

## 2. Materials and Methods

### *2.1. Methodology for Determining $NH_3$ Emissions by Calculation from Measurements of the Internal $NH_3$ Concentration*

Two approaches were used to monitor $NH_3$ emissions by intensive fattening pig farms. The first approach was breeding monitoring, chosen arbitrarily during the fattening cycle and focused mainly on the final stages. This is mainly because the final phase is expected to produce more $NH_3$ emissions, and thus has a more representative impact on the environment and the possibility of comparison with emission limits.

The second approach was based on the monitoring of $NH_3$ emissions according to BREF IRPP [17] and BAT conclusions under Directive 2010/75/EU [22]. The basis of the methodology is to take measurements during six days of the period of interest (year). Fattening pigs are classified as breeding with a linear increase in $NH_3$ emissions. The sampling days will be evenly distributed over the growing season. Half of the measurements shall be taken in the first half of the breeding cycle and the remainder in the second half. The sampling days in the second half of the breeding cycle shall be evenly distributed throughout the year (same number of measurements per season). The daily average was calculated as the mean overall sampling days.

### *2.2. Methodology Measurement of the $NH_3$ Concentration and Calculation of $NH_3$ Emissions*

For assessing $NH_3$ emissions, it is essential to follow the methodology set out in BREF IRPP [17] and BAT conclusions under Directive 2010/75/EU [22]. Therefore, it is essential to determine the $NH_3$ concentrations at the inlet and outlet of the stable and to measure the airflow out of the stable at the same time for a period of 24 h.

For the measurement of $NH_3$ was used the photoacoustic multi-gas monitor INNOVA 1512 by Advanced Energy Industries, Inc, United States of America. The instrument works based on the principle of the infrared photoacoustic method. It is supplemented by a switch of measuring points Innova Multipoint Sampler 1409 D with the possibility of taking air samples from up to twelve places. The device continuously uploads the measured values to its internal memory, and the sampling frequency was set to 6 min. The flow meter was used to analyze the airflow from the stable by TESTO 445, TESTO AG, Lenzkirch, Germany.

Climatic and microclimatic conditions were also monitored during the measurements (temperature, relative humidity, and atmospheric pressure) by COMMETER D4141 and COMMETER S3120 COMET SYSTEM spol. s r.o., Rožnov pod Radhoštěm, Czech Republic.

For the calculation of $NH_3$ emissions, a methodology [25] was selected based on the BREF IRPP. It also details how the measured data were evaluated during the 24 h measuring cycle.

The $NH_3$ emission rate $E$ (mg·s$^{-1}$) can be now figured out from this formula:

$$E = (C_{OUT} - C_{IN}) \cdot v \cdot S, \tag{4}$$

where $C_{OUT}$ is $NH_3$ concentration in an outlet (mg·m$^{-3}$), $C_{IN}$ is $NH_3$ concentration in the input (mg·m$^{-3}$), $v$ is the air velocity caused by the stable ventilation (m·s$^{-1}$), and $S$ is the area of the exhaust of the ventilation (m$^2$).

The arithmetic mean and standard deviation are determined from all obtained values of effective emissions during one day (24 h). Subsequently, the total production-specific emissions per year $E_{YEAR}$ (kg $NH_3$·animal$^{-1}$·year$^{-1}$) are determined and converted to a value per pig using this formula:

$$E_{YEAR} = E_{AVG} \cdot N^{-1}, \tag{5}$$

where $E_{AVG}$ is the arithmetic mean of the $E$ (kg $NH_3$·year$^{-1}$), and $N$ is the number of pigs housed in the stable.

### 2.3. Experimental Pig Houses

Monitoring of $NH_3$ emissions was carried out in intensive fattening pig farms located in the South Bohemia region in the Czech Republic. Different BATs were used in the breeding, see Table 1. Two approaches were used for this monitoring:

(1) The first approach aimed to monitor breeding farms by using measurements in the final fattening phase to represent the farm in terms of $NH_3$ emissions. These breeding farms are listed below.

The farm in Jindřichův Hradec district (420 m above sea level) was equipped with a fully slated floor with a deep pit (BAT 30.a0) in a combination with feed additives Axtra Phy (Danisco Animal Nutrition, Marlborough, Great Britain), BioAktiv (BioAktiv GmbH. Zeitz, Germany), Fresta F Plus (Delacon Biotechnik GmbH, Engerwitzdorf, Austria), and Algitek AD (Tekro s.r.o., Prague, the Czech Republic). Air exchange is provided by forced negative pressure ventilation. There are seven ceiling fans with a diameter of 0.4 m in the breeding pen.

In the Tábor district, there were two farms (first farm Tábor No.1, second farm Tábor No.2). Tábor farm No. 1 (424 m above sea level) had a slated floor with a deep pit (BAT 30.a0) in combination with feed additives Synergen (Alltech, Inc., Nicholasville, KY, USA) and Fortibach F Plus (Addicoo Group s.r.o., Sumperk, the Czech Republic). Air exchange is provided by forced positive pressure ventilation. There are five ceiling shafts in the breeding pen with a diameter of 0.5 m × 0.5 m. Fresh air is supplied by four side fans with a diameter of 0.4 m.

The Tábor farm No. 2 (439 m above sea level) used a deep litter on a solid concrete floor (BAT 30.a8) in combination with feed additives 6-Phytase 1500 FTU (Danisco Animal Nutrition, Great Britain) and Quantum Blue (Roal Oy, Rajamäki, Finland). Air exchange is provided by forced positive pressure ventilation. There are four ceiling shafts in the breeding pen with a diameter of 0.5 m × 0.5 m. Fresh air is supplied by four side fans with a diameter of 0.35 m.

Příbram district (470 m above sea level) had a farm with a fully slated floor with a deep pit (BAT 30.a0) in combination with feed additives Natuphos (BASF a.g, Düsseldorf, Germany) and Quantum Blue (Roal Oy, Rajamäki, Finland). Air exchange is provided by forced negative pressure ventilation. In the breeding pen, there are four under-slatted fans with a diameter of 0.6 m. Fresh air is supplied by ten wall flaps with a dimension of 0.9 m × 0.3 m.

(2) The second approach aimed to monitor farms that have been monitored according to BREF IRPP [17] and BAT conclusions under Directive 2010/75/EU [22] methodology, which specifies an even distribution of six sampling days over the growing season (same number of measurements per season). Half of the measurements have been performed in the first half of the breeding cycle and the rest in the second half.

Monitoring was carried out on the farm located in the České Budějovice district (438 m above sea level). The farm was equipped with a fully slated floor with a deep pit (BAT 30.a0) in a combination with feed additives 6-Phytase 1 500 FTU (Danisco Animal Nutrition, Marlborough, Great Britain) and Forbtibach F Plus (Addicoo Group s.r.o., Sumperk, the Czech Republic). Air exchange is provided by forced negative pressure ventilation. In the breeding pen, there are eight ceiling fans with a diameter of 0.7 m. Fresh air is supplied by side flaps on both sides of the hall (18 pieces) with a dimension of 0.3 m × 0.6 m.

**Table 1.** BAT applications in selected breeds.

| Districts | Designation of BAT for Housing | Effectiveness in Reducing $NH_3$ Emissions by Using BAT for Housing (%) | Feed Additives | Effectiveness in Reducing $NH_3$ Emissions by Using Feed Additives (%) |
|---|---|---|---|---|
| Jindřichův Hradec | BAT 30.a0 | 25 | Axtra Phy<br>BioAktiv<br>Fresta F Plus<br>Algitek AD | 23<br>27<br>27<br>45 |
| Tábor (Farm No. 1) | BAT 30.a0 | 25 | Synergen<br>Fortibach F Plus | 39<br>48 |
| Tábor (Farm No. 2) | BAT 30.a8 | 0 | 6-Phytase 1500 FTU<br>Quantum Blue | 23<br>22 |
| Příbram | BAT 30.a0 | 25 | Natuphos<br>Quantum Blue | 29<br>22 |
| České Budějovice | BAT 30.a0 | 25 | 6-Phytase 1500 FTU<br>Fortibach F Plus | 23<br>48 |

### 2.4. *Methodology for Estimation of $NH_3$ Emissions by Using Emission Factors*

The third approach was determined according to the estimation by emission factors that are valid in the Czech Republic [24] and respect BREF IRPP [17]. Emission factor is determined based on scientific knowledge and varies according to the category of animals, the number of animals, and the occupancy during the year. These factors (Table 2) were established in the Czech Republic in the past on the basis of experimental measurements made to represent local breeding conditions.

**Table 2.** Emission factors specified in the Czech Republic in (kg $NH_3 \cdot animal^{-1} \cdot year^{-1}$) [24].

| Animal Category | Housing | Manure Storage | Landspreading |
|---|---|---|---|
| Piglets | 2.0 | 2.0 | 2.5 |
| Sows | 4.3 | 2.8 | 4.8 |
| Gestating sows | 7.6 | 4.1 | 8.0 |
| Fattening pigs | 3.2 | 2.0 | 3.1 |

In the Czech Republic, from the breeding process of fattening pig's, the total emission factor is determined at 8.3 kg $NH_3 \cdot animal^{-1} \cdot year^{-1}$. Of those, 3.2 kg $NH_3 \cdot animal^{-1} \cdot year^{-1}$ represents $NH_3$ emissions from housing, 2.0 kg $NH_3 \cdot animal^{-1} \cdot year^{-1}$ from manure storage, and 3.1 kg $NH_3 \cdot animal^{-1} \cdot year^{-1}$ from landspreading. For the purpose of this study, an emission factor is considered that represents the $NH_3$ emissions from the housing (3.2 kg $NH_3 \cdot animal^{-1} \cdot year^{-1}$) [24]. According to [24], the emission factor from each area (housing, manure storage, landspreading) may be reduced by the BAT used. The farmer can use a combination of reducing BAT based on the housing system and BAT based on feeding measures in the stables. Since the exact effect level of both reducing BAT cannot be determined, only the one with the higher reducing effect is counted in the calculation.

## 3. Results

### *3.1. Climatic and Microclimatic Conditions*

As mentioned in the previous chapter, the climatic and microclimatic conditions (temperature, relative humidity, atmospheric pressure, air velocity) that prevailed during each measurement were also monitored in each studied area. Table 3 shows the values for the farms that were selected in terms of similar age and weight groups during arbitrary monitoring. Table 4 shows the values for the farm in České Budějovice district, where two complete breeding cycles were monitored in each of the two sections that could be monitored during the year.

**Table 3.** Climatic and microclimatic conditions during the first approach monitoring.

| Districts | Number of Pigs (pc) | Weight (kg) | Outdoor Temperature (°C) | Indoor Temperature (°C) | Outdoor Humidity (%) | Indoor Humidity (%) | Atmospheric Pressure (hPa) | Airflow Rate ($m^3 \cdot s^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| Jindřichův Hradec | 450 | 100.0 | −0.7 | 9.3 | 90.4 | 70.8 | 972.2 | 6.80 |
| | 703 | 90.0 | 5.3 | 12.3 | 53.3 | 57.9 | 964.1 | 7.26 |
| Tábor (Farm No. 1) | 196 | 102.0 | 16.5 | 19.1 | 39.1 | 70.0 | 968.5 | 2.36 |
| | 198 | 102.0 | −0.9 | 20.8 | 35.1 | 65.2 | 968.5 | 3.55 |
| Tábor (Farm No. 2) | 256 | 90.0 | 18.3 | 21.1 | 48.1 | 55.7 | 969.7 | 19.07 |
| Příbram | 156 | 91.0 | 15.2 | 23.2 | 31.1 | 58.9 | 963.4 | 1.90 |

**Table 4.** Climatic and microclimatic conditions during the second approach monitoring.

| Breeding Section | Breeding Cycle | Number of Pigs (pc) | Weight (kg) | Outdoor Temperature (°C) | Indoor Temperature (°C) | Outdoor Humidity (%) | Indoor Humidity (%) | Atmospheric Pressure (hPa) | Airflow Rate ($m^3 \cdot s^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 676 | 25.0 | 0.4 | 17.1 | 68.6 | 70.8 | 967.9 | 1.13 |
| | | 627 | 51.0 | 0.5 | 20.6 | 94.0 | 67.5 | 942.7 | 1.72 |
| | | 579 | 75.1 | 10.2 | 17.7 | 47.1 | 57.8 | 967.5 | 1.75 |
| | | 560 | 99.3 | 17.1 | 21.6 | 31.3 | 42.1 | 967.2 | 19.85 |
| | | 558 | 103.2 | 22.5 | 24.2 | 51.2 | 66.7 | 965.5 | 21.42 |
| | 2 | 680 | 18.0 | 17.1 | 18.7 | 73.1 | 75.7 | 964.1 | 6.01 |
| | | 653 | 33.2 | 26.6 | 24.8 | 54.3 | 63.0 | 965.7 | 19.86 |
| | | 611 | 70.7 | 21.4 | 21.4 | 49.6 | 57.0 | 972.5 | 19.31 |
| | | 606 | 88.7 | 14.0 | 20.0 | 57.3 | 58.4 | 968.4 | 9.31 |
| | | 559 | 120.0 | 12.1 | 19.6 | 84.5 | 64.1 | 961.8 | 7.92 |
| 2 | 1 | 676 | 25.0 | 0.4 | 19.2 | 68.6 | 75.7 | 966.8 | 1.03 |
| | | 599 | 49.6 | 0.5 | 21.1 | 94.0 | 64.2 | 943.2 | 1.70 |
| | | 576 | 73.3 | 10.2 | 17.2 | 47.1 | 52.2 | 968.8 | 1.70 |
| | | 536 | 97.3 | 17.1 | 21.0 | 31.3 | 44.9 | 967.5 | 19.80 |
| | | 533 | 102.9 | 22.5 | 25.0 | 51.2 | 60.4 | 965.7 | 21.39 |
| | 2 | 680 | 21.0 | 17.1 | 17.1 | 73.1 | 77.6 | 965.8 | 6.20 |
| | | 659 | 35.2 | 26.6 | 25.4 | 54.3 | 66.1 | 965.8 | 19.80 |
| | | 630 | 64.7 | 21.4 | 21.7 | 49.6 | 58.5 | 972.5 | 15.33 |
| | | 606 | 94.7 | 14.0 | 19.9 | 57.3 | 57.3 | 968.5 | 9.81 |
| | | 545 | 112.0 | 12.1 | 17.3 | 84.5 | 69.9 | 961.8 | 7.95 |

### *3.2. Results of $NH_3$ Emissions Values*

The resulting calculated $NH_3$ emissions values for both monitoring groups are presented in Tables 5 and 6. They have listed different breeding and feed technologies, including the feed additives used and their percentage of effectiveness in reducing $NH_3$ emissions.

**Table 5.** Results of the calculated $NH_3$ emission from the first approach monitoring.

| Districts | Weight (kg) | Date of Measurement | $NH_3$ Emissions (kg $NH_3 \cdot animal^{-1} \cdot year^{-1}$) |
|---|---|---|---|
| Jindřichův Hradec | 100 | 10–11 February | 1.92 ± 0.01 |
| | 90 | 9–10 May | 1.00 ± 0.04 |
| Tábor (Farm No. 1) | 102 | 14–15 February | 1.75 ± 0.04 |
| | 102 | 4–5 September | 3.51 ± 0.03 |
| Tábor (Farm No. 2) | 90 | 3–4 July | 2.03 ± 0.08 |
| Příbram | 91 | 13–14 September | 1.45 ± 0.03 |

**Table 6.** Results of the calculation of $NH_3$ emission from the second approach monitoring.

| Section | Breeding Cycle | No. of Measurement | Weight of Pigs (kg) | Date of Measurements | Calculated $NH_3$ Emission According to BREF IRPP (kg $NH_3 \cdot animal^{-1} \cdot year^{-1}$) | Measured $NH_3$ Emission (kg $NH_3 \cdot animal^{-1} \cdot year^{-1}$) |
|---|---|---|---|---|---|---|
| 1 | 1 | A1 | 25.0 | 8–9 February | 0.91 ± 0.02 | 0.18 ± 0.02 |
| | | A2 | 51.0 | 6–7 March | | 0.13 ± 0.01 |
| | | A3 | 75.1 | 5–6 April | | 0.18 ± 0.03 |
| | | A4 | 99.3 | 7–8 May | | 0.77 ± 0.04 |
| | | A5 | 103.2 | 31 May–1 June | | 0.67 ± 0.02 |
| | 2 | A6 | 18.0 | 11–12 June | | 0.71 ± 0.03 |
| | | A7 | 33.2 | 8–9 August | | 1.67 ± 0.03 |
| | | A8 | 70.7 | 11–12 September | | 1.71 ± 0.03 |
| | | A9 | 88.7 | 16–17 October | | 2.22 ± 0.02 |
| | | A10 | 120.0 | 6–7 November | | 1.06 ± 0.02 |
| 2 | 1 | A11 | 25.0 | 8–9 February | 1.03 ± 0.03 | 0.21 ± 0.02 |
| | | A12 | 49.6 | 6–7 March | | 0.22 ± 0.02 |
| | | A13 | 73.3 | 5–6 April | | 0.23 ± 0.03 |
| | | A14 | 97.3 | 7–8 May | | 1.35 ± 0.04 |
| | | A15 | 102.9 | 31 May–1 June | | 1.49 ± 0.02 |
| | 2 | A16 | 21.0 | 11–12 June | | 0.65 ± 0.03 |
| | | A17 | 35.2 | 8–9 August | | 3.10 ± 0.04 |
| | | A18 | 64.7 | 11–12 September | | 1.93 ± 0.03 |
| | | A19 | 94.7 | 16–17 October | | 2.12 ± 0.03 |
| | | A20 | 112.0 | 6–7 November | | 1.49 ± 0.02 |

The measurements of $NH_3$ emissions during the breeding cycle in the České Budějovice district from fattening pigs have been investigated too. The investigation was performed for two breeding cycles in one section and two breeding cycles in the second section. For each breeding cycle, the measurements of five repetitions were performed. The first fattening cycle occurred between February and June; the second one was between June and November. A total of 20 measurements were taken here, monitoring fattening pigs in two breeding sections. The authors managed to monitor two complete fattening cycles in each breeding section. For experimental reasons, the number of measurements was overestimated compared with the above-mentioned methodology. Otherwise, three measurements for each breeding cycle would have been sufficient.

To calculate the $NH_3$ emissions in accordance with the BREF IRPP [17] and BAT conclusions under Directive 2010/75/EU [22] methodology, regarding Section 1, the first three measurements from the first breeding cycle (No. A1, A2, A3) and the last three measurements from the second breeding cycle (No. A8, A9, A10) were used. A similar procedure was followed for Section 2.

## 4. Discussion

To determine $NH_3$ emissions from intensive livestock breeding, methodologies have been developed to estimate these emissions based on the data from the operating conditions. In general, $NH_3$ emissions can be determined by calculation from measurements of the internal $NH_3$ concentration in the breeding house, emission factors, or using a mass balance based on the total nitrogen.

In the Czech Republic, emission factors are mainly used to determine $NH_3$ emissions. This approach is popular because of its financial and time-saving benefits. The emission factors are set out in the national protocol [24]. For our analysis, we will only use an emission factor that considers the air emissions from the stables (3.2 kg $NH_3 \cdot animal^{-1} \cdot year^{-1}$). Technologies used to reduce $NH_3$ emissions are also considered; therefore, this value will be reduced by the BAT used. The farmer can use a combination of BAT reducing emissions from the housing system. Since the exact effect level of more reducing BATs cannot be determined, only the one with the higher reducing effect is counted in the calculation.

Table 7 shows that the emission factors are set for farming conditions that do not use any BAT. Therefore, it is advantageous for the farmers to reduce the calculated emissions by the efficiency of the most efficient BAT. It can also be seen that even if some $NH_3$ emission values exceed the stated value of emission factor of 3.2 kg $NH_3 .animal^{-1} \cdot year^{-1}$ during monitoring, this value is overestimated in terms of the evolution of emissions over the entire breeding period. Exceedances occur mainly at the end of the fattening period in the summer months. From a theoretical point of view, it is clear that combining BAT for housing and feeding results in more significant emission reductions than farmers can account for in the final calculations, where they can only apply a percentage reduction for the more efficient BAT. Estimating realistic emission reductions using BAT for feed is challenging, as farmers combine different feed additives with varying effectiveness in reducing $NH_3$ emissions.

**Table 7.** Determination of $NH_3$ emissions (kg $NH_3 \cdot animal^{-1} \cdot year^{-1}$) calculation by measuring in comparison with estimation by emission factors.

| Districts | $NH_3$ Emissions Calculation by Measuring —First Approach | $NH_3$ Emissions Calculation by Measuring —Second Approach | Emission Factor for Housing —Third Approach | Estimated Reduced Emissions —Feed Additives |
|---|---|---|---|---|
| Jindřichův Hradec | $1.92 \pm 0.01$<br>$1.00 \pm 0.04$ | -<br>- | 3.2<br>3.2 | 1.76–2.46 |
| Tábor (Farm No. 1) | $1.75 \pm 0.04$<br>$3.51 \pm 0.03$ | -<br>- | 3.2<br>3.2 | 1.66–1.95 |
| Tábor (Farm No. 2) | $2.03 \pm 0.08$ | - | 3.2 | 2.46–2.50 |
| Příbram | $1.45 \pm 0.03$ | - | 3.2 | 2.27–2.50 |
| České Budějovice (Section 1) | - | $0.91 \pm 0.02$ | 3.2 | 1.66–2.46 |
| České Budějovice (Section 2) | - | $1.03 \pm 0.03$ | 3.2 | |

It depends on each EU member's approach whether it will be used to determine $NH_3$ emissions based on emission factors derived according to a national or an international protocol [23,26]. In general, it would be advisable to update the established emission factors at the national level in order to refine the overall estimate of emissions, even if this is time-consuming and costly [27].

Table 7 and, respectively, Figures 1 and 2, also show that it is more objective to use BREF IRPP [17] and BAT conclusions under Directive 2010/75/EU [22] methodology to determine $NH_3$ emissions (six sampling days over the growing season). One measurement, for example, taken at the start of the fattening period in colder conditions, may be quite different from a measurement taken in summer weather. These differences may become more pronounced with the length of the fattening period. Interestingly, even breeding sections in one breeding building with similar microclimatic conditions and identical breeding and fattening technology show differences in $NH_3$ emissions. From Figures 1 and 2, the breeding houses are labeled A4/A14, A5/A15, A7/A17, and A10/A20. On detailed examination, it was found that the internal conditions were at the limit of moderate thermal stress when measurements A4/A14, A5/A15, and A7/A17 were made. This may have caused each group of pigs to react differently to this phenomenon, and, therefore, such different values may have been measured.

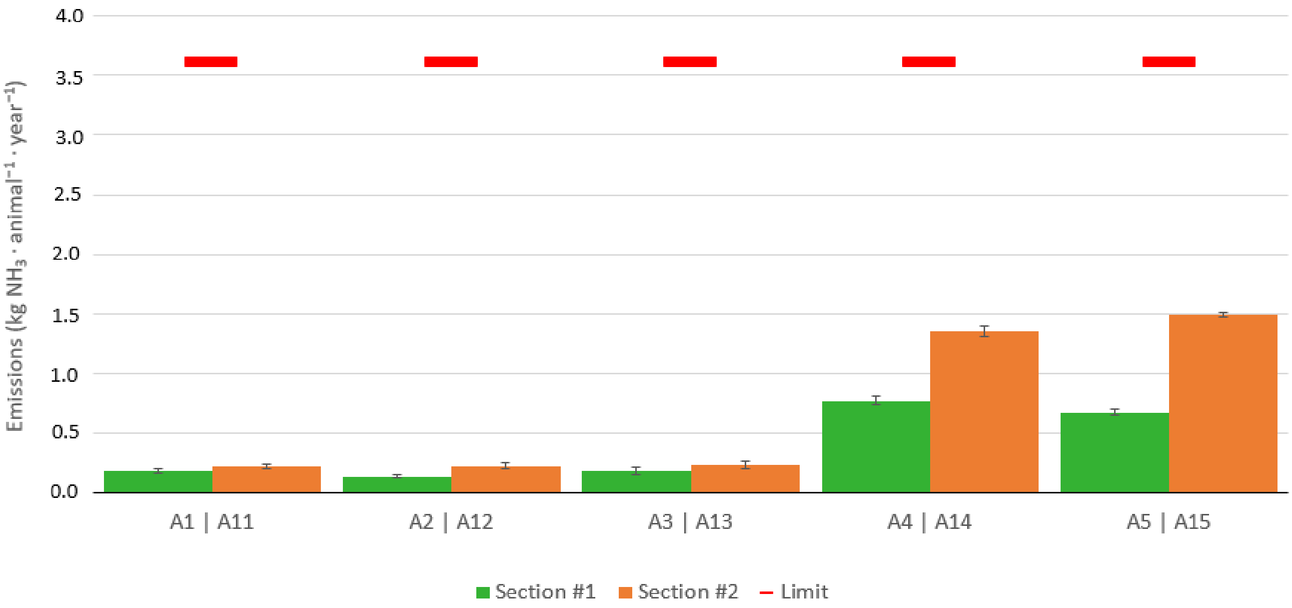


**Figure 1.** $NH_3$ emissions between February and June in 1st breeding cycle.

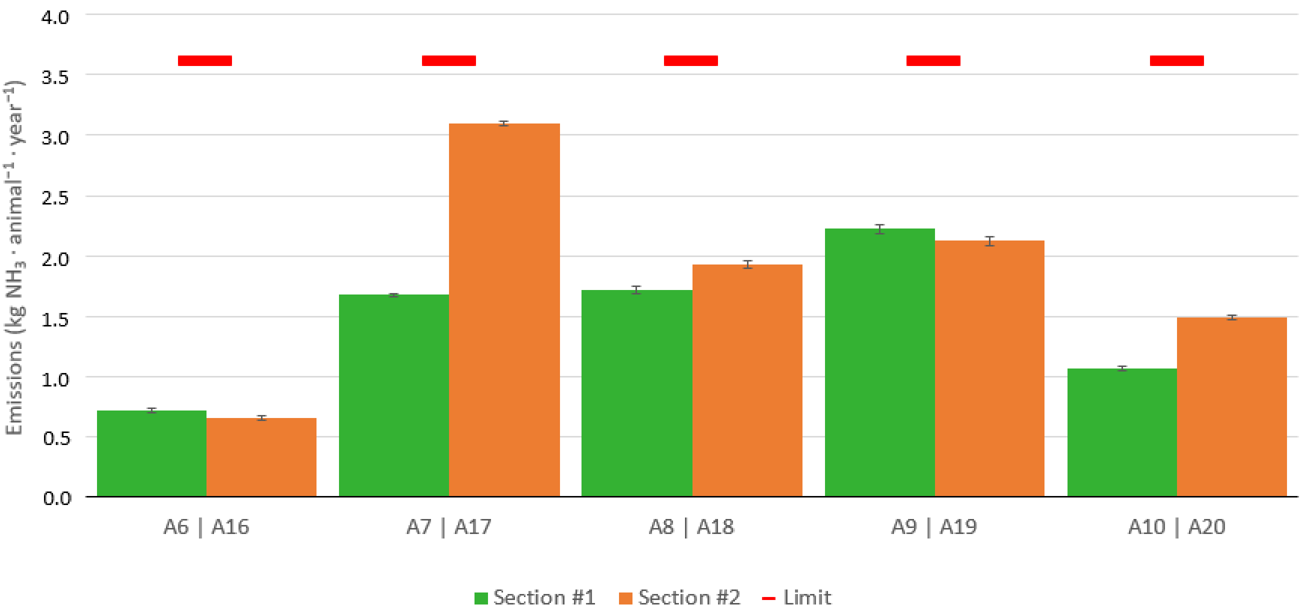


**Figure 2.** $NH_3$ emissions between June and November in 2nd breeding cycle.

According to [28], $NH_3$ emissions from confined livestock buildings used for fattening pigs production are expected to increase by about 15% to 20% due to the increasing temperature. Our study has also shown that climatic and microclimatic conditions can affect $NH_3$ emissions, particularly the values from monitoring whole fattening cycles shown in Figures 1 and 2. Since the monitoring of the breeding cycle was carried out in the February to June period and the second breeding cycle in the June to November period, these values can be considered conclusive and attribute a non-negligible influence on the production of $NH_3$ emissions to the time of the year.

The above aspects support the approach of the BREF IRPP [17] and BAT conclusions under Directive 2010/75/EU [22] methodology, according to which half of the measurements should be taken during the first and the other half during the second phase of the breeding cycle and still be planned throughout the year. There have been many studies on this issue that have aimed to optimize the monitoring process, see [23,29–31], and are based on the following assumptions.

The method of *intermittent measurements* from establishing a model for determination of $NH_3$ emissions from fattening pigs. This model entered data from twelve measurements taken from the entire fattening period. Maximum model error of 10% was determined between simulated and measured $NH_3$ emissions [30].

## 5. Conclusions

Nowadays, the determination of $NH_3$ emissions from livestock farms is a topical issue due to the reduction efforts. Large-scale farmers in the Czech Republic are obliged to estimate these emissions annually and report them to the competent authority. In particular, the following are used to determine their estimation by using emission factors, because it is a very simple and inexpensive method, but as our study confirms, also inaccurate.

Another option that was tested in our study is to use calculation by measuring the $NH_3$ concentration. This option is costly and time-consuming but the most accurate. However, as we argue in our study, it should be implemented following BREF IRPP [17] and BAT conclusions under Directive 2010/75/EU [22]. When planning the measurements, it is essential to reflect on the different fattening phases and the seasons. Experiments have confirmed this theory, because taking measurements only in a specific part of the fattening cycle or only in a particular season can significantly distort the result.

The results of the study that indicate emission factors for determining $NH_3$ emissions from the housing may be overestimated. The Czech Republic is currently reviewing these emission factors to refine these calculations. As breeding feeding practices relating to the conversion of nutrients by animals continue to be modernized, it may be that these emission factors do not correspond to reality. Experience shows that each country should have its emission factors due to the different breeding technologies used, climatic conditions, and pig breeds and hybrids. Together with efforts to update them, this should ensure that $NH_3$ emissions are estimated as accurately as possible. It is also challenging to consider a more significant number of BAT when estimating $NH_3$ emissions, where only BAT with the highest efficiency in reducing $NH_3$ emissions was considered in the calculations. However, it is assumed that other BAT also contributes to their elimination somehow. Unfortunately, there are so many variables influencing the production of $NH_3$ emissions that it is difficult to investigate this issue more experimentally.

An approach that could improve the accuracy of statistical data on emissions production from intensive livestock farms covered by the IPPC is the refinement of emission factors by individual countries, which is widespread for determining these monitored emissions.

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