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Survey of applied ammonia mitigation technologies in the Hungarian pig production practice

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Abstract: The Directive on National Emission Ceilings specifies the reduction of ammonia (NH_3) emissions among other air pollutants, which is most significant for the agricultural sector. The ammonia emission limit set for Hungary was a 10% reduction by 2020, while the target of 32% should be reached by 2030 compared to the 2005 reference year. The paper presents the results of a survey on pig production technology in Hungary from 97 domestic farms. The study aims to know the level of implementation of reduction techniques in livestock production and manure management and highlights the need for further improvements in this production sector. The research found that the application of ammonia reduction techniques was not considered widespread, either in livestock buildings or in manure storage (treatment) and during field application. For almost all (more than 90%) pig production groups, the housing systems were the reference without additional emission reduction. For manure storage, farms have insulated storage under the current regulation, however, significantly more emission reduction technologies were in the variant without cover or crust. Slurry spreading was mainly used with manure application techniques, but more emission-friendly injection and band spreading were also emerging. Besides the expected immediate incorporation, a high proportion of manure was applied between 12 and 24 hours or even after 24 hours. In the studied elements of manure management, significant improvements are needed in applying techniques to reduce ammonia emissions. Effective results can be achieved even by shortening the time between manure application and incorporation with efficient work organization.

Introduction

The main source of ammonia and greenhouse gas (GHG) emissions is livestock production (Sajeev et al. 2018). A similar finding that livestock farming and related manure management are a major source of atmospheric ammonia was made by Sommer and Hutchings (2001) and Velthof et al. (2012). The paper by Insausti et al. (2020) put the ammonia in the atmosphere from an agricultural source at around 90%. Ammonia gas emissions from manure management have been the topic of intensive research worldwide for decades, considering this gas as the main pollutant of agricultural origin, which has a long-range impact on the environment (terrestrial and aquatic systems), on human health and is also a major contributor to soil acidification, eutrophication, and loss of biodiversity (Sutton et al. 2011, WHO 2013)

The treatment of animal manure (in slurry or solid manure form) involves many environmental issues, as, if mishandled, various nutrients and organic compounds cause pollution through ammonia and greenhouse gases emissions. At all stages of the manure management chain (animal housing, storage and processing, field application), there are released gases that need to be reduced. If manure is not handled correctly, the emissions saved at each stage (s) may be released later (Sajeev et al. 2018).

Policies have been developed for all European Union (EU) member states to reduce emissions from manure management. Sajeev et al. (2018) summarized that Gothenburg Protocol under the Convention on Long-Range Transboundary Air Pollution or the National Emission Ceilings Directive were considered in developing each national policy. Other indirect policies such as the Nitrate Directive, Directive on Integrated Pollution Prevention and Control, Water Framework Directive, and, finally, the Common Agricultural Policy also have an influential effect on ammonia emissions. To achieve the reduction targets, the United Nations Economic Commission for Europe (UNECE) issued in 2014 a framework for good agricultural practices to reduce NH3 emissions entitled "Options for Ammonia Mitigation Guidance from the UNECE Task Force on Reactive Nitrogen" (Bittman et al. 2014). According to the NEC Directive 2016/2284, each member state must develop a national code of good agricultural

practices to reduce ammonia emissions to manage the whole life cycle of nitrogen. Improvements and reduction procedures need to be implemented based on Bittman et al. (2014), which includes enhancing livestock feed strategies, low-carbon manure storage, application techniques, implementing low-emission animal housing, and reducing emissions from the use of mineral fertilizers.

According to the Informative Inventory Report (Hungarian Meteorological Service 2020), 92% of the Hungarian total NH_3 emissions were derived from agriculture (grazing, livestock farming manure management, manure and inorganic fertilizer application). Examining the data for 2019, 45% of the national NH_3 emissions are from animal production, of which pigs accounted for 23%.

Hungary's national ammonia emissions are to be reduced by 32% till 2030, compared to the 2005 basic year (NEC directive 2016). The provisions are summarized in the National Air Pollution Control Program – Agricultural Subprogram (Előry et al. 2020). This commitment is the largest in Europe (EC 2016), significantly impacting Hungarian pig farming and proper manure management technology development.

Guideline for Determining the Best Available Techniques in the Process of Authorisation of Intensive Rearing of Pigs document also sets emission limit values for excreted nitrogen and ammonia emissions from pig buildings where interventions were required and proposals for measures at the levels of the manure management chain formulated. Despite the 6 million pigs identified in the „Pig Farming Strategy" as an option for economic feed use, Hungary's pig population has stagnated at around 3 million in the last decade due to several influencing factors. An essential factor is the fact that more than 70% of the domestic pig population is kept on intensive rearing farms under the Integrated Pollution Prevention and Control (IPPC) Directive (Ministry of Agriculture 2020).

Research on manure management and its emission relationships has been of paramount importance for decades, but there is still a lack of accurate information on the data and technologies used in each region. However, there have been recent developments in this area, and it is sufficient to look at an analytical study on Poland (Mielcarek-Bocheńska et al. 2019) or research on the prevalence of manure treatment techniques in France (Loyon 2018). In order to maintain and possibly increase the volume of emissions from pig farming and the entire livestock sector, it is essential to take stock of the current use of emission technologies for sustainable production processes and to examine their further applicability.

The present study seeks to provide important information on the prevalence of technologies for limiting the release of undesirable substances (ammonia) into the environment. The classification was not based on specific on-site emission measurements, but the accepted evaluation of the individual technical solutions based on Bittman et al. (2014), so the statistical analysis of the applied practical versions were performed. Our work aimed to promote compliance with the National Emission reduction Commitments (NEC) Directive, which are the strictest in the EU, by establishing a representative survey of domestic pig farming to determine the extent of the use of techniques that have been proven to reduce ammonia emissions during husbandry technology, manure treatment and manure application. Following the survey, the intervention points with the most significant potential in pig farming can be identified. The results may contribute to specifying the ammonia emissions from pig production practice in the National Inventory Report and identifying domestic development and support areas.

Material and methods

Data selection method

The technology survey selection was made representatively, considering the national situation, housing technology and farm size. Our sampling aimed to deduce from the results obtained while examining a sample population representing the base population, but with smaller elements; the base population's properties are considered relevant for ammonia emissions. This estimation was based on probability calculation principles, so in theory, selecting the sample itself could only be a random method. Finally, 97 agricultural enterprises took part in the research using the multi-stage random selection method. The research was carried out in 2017. The analyses are based on livestock size, management system and emission factors at all manure chain stages. Besides the primary data (farm location, livestock data), the survey included housing technology management practices, manure storage with treatment and application. Emissions from grazing were excluded from the investigation. Not the entire production chain was examined, only techniques from housing technology to the application were considered. However, the UNECE Guidance included only on a supplementary level the manure treatment topic (reference technique: untreated slurry or solid manure), as it addresses greenhouse gases besides ammonia, but the survey also looked at this area.

Techniques relevant to the emission reduction (from UNECE category 1 and 2) were considered, as defined by Bittman et al. (2014), as well as the related literature (Fenyvesi et al. 2003, Santonja et al. 2017) and the existing typical national production practice.

In studied domestic farms there were housed 532,000 pigs (Tab. 1), representing about 19% of the Hungarian Central Statistical Office (HCSO) stock data from June 2017. The proportion of the sample exceeded 10% in all pig production groups. The Pearson correlation value confirmed the surveyed sample's representativeness compared to the total pig numbers $r = 0.99$; $p < 0.01$.

The geographical distribution was adapted to the size of the livestock (Fig. 1). For comparability, the pig production groups in each farm were converted to livestock units (LSU).

Data evaluation

For data analysis, it was necessary to convert the animal husbandry categories used in the pig farming practice into the animal categories used by the HCSO. These pig categories were as follows: piglets under 20 kg, young pigs between 20 and 50 kg, pigs for fattening over 50 kg, sows mated for the first time, empty sows, gestating sows, gilts not yet mated and breeding boar (not part of the UNECE document, so not covered by the analysis). The conversion has been completed with the data of performance based on Benedek et al. (2016), Hegedűsné Baranyai et al. (2016) and Koltay et al. (2018). Janni and Cortus (2020) described that pig housing systems

typically segregate animals into different facilities in line with the pig life cycle phase. The analyses were also performed in this way.

Data analysis was carried out along three main categories: housing, manure storage with treatment and manure field application techniques.

Statistical analysis

Statistical analysis was conducted using the SPSS 25.0 software package (IBM Corporation, Armonk, NY, USA). To establish the representativeness of the data, bivariate Pearson Correlation was used. To compare manure storage solutions and field application technologies, non-parametric repeated measures ANOVA tests (Friedman *rank*-sum test) were used. Because the p-value was significant, a pairwise comparison was performed with a two-sample non-parametric test (Wilcoxon signed-rank test) correction to clarify the difference.

Results

Housing technology

Predominantly the reference, standard pig housing technologies were found in more than 90% of the surveyed farms in all age groups (Tab. 2), including methods to remove manure without any other UNECE emission reduction technology. Within this, the use of littering system was relatively high (e.g., in the case of fattening pigs it was 16.4%).

Among UNECE's emission reducing technologies, the highest proportion was observed in the sows mated for the first time with 8.1%. In the remaining pig age groups, their share was around only 5–6.6%.

Manure storage and treatment

Figure 2 shows the distribution of slurry storage techniques. As a result of the *Friedman rank*-sum test, we found a significant

Table 1. Age and sex distribution of pig population

Pig age groups	Total number [Thousand pieces, June 2017]	Number of samples [Thousand pieces]	Distribution [%]
Piglets under 20 kg	704.8	114.722	16.3%
Young pigs; 20–50 kg	661.2	144.366	21.8%
Pigs for fattening, over 50 kg	1 184.1	219.246	18.5%
Gestating sows	133.8	20.384	15.2%
Empty sows	41.8	6.419	15.4%
Gilts not yet mated	40.9	9.964	24.4%
Sows mated for the first time	37.0	16.744	45.3%

source: Hungarian Central Statistical Office 2018
remark: Pig age groups were named based on the Hungarian National Inventory report

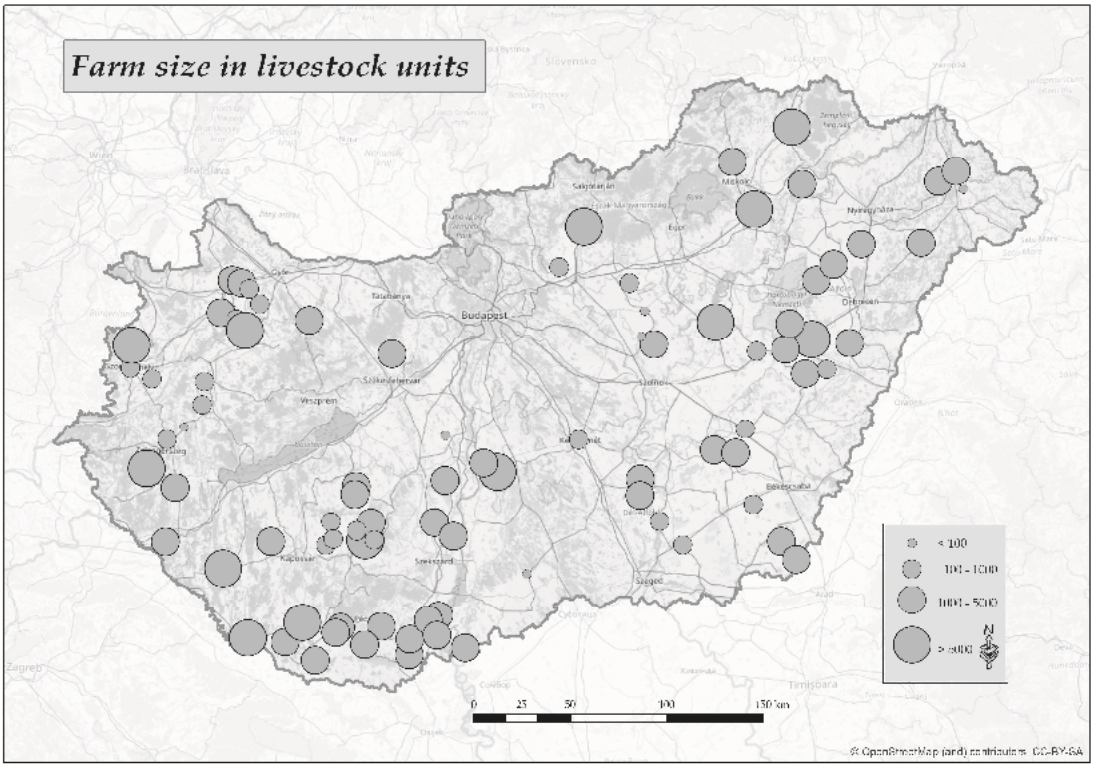


Fig. 1. Farm size in the livestock units

Table 2. Distribution of pig farming technologies in the surveyed farms

Pig housing techniques			Gestating sows (%)	Empty sows (%)	Sows mated for the first time (%)	Piglets (%)	Young pigs (%)	Pigs for fattening (%)	Gilts not yet mated (%)
Reference pig housing technologies	Solid manure	Daily manure removal	12.6	13.8	9.7	3.9	7.0	11.4	22.8
		Non-daily manure removal	N/A	N/A	N/A	N/A	1.4	2.9	N/A
		Built-up litter	N/A	N/A	N/A	N/A	N/A	0.1	N/A
		Deep litter manure	2.1	1.3	0.3	0.3	0.7	2.0	0.7
	Slurry	Fully slatted floor, pit, <1 month	15.7	48.2	25.1	25.4	28.8	19.7	11.8
		Fully slatted floor, pit, >1 month	23.0	19.5	18.0	53.3	32.8	25.2	18.0
		Partly slatted floor, pit, <1 month	12.8	3.9	8.9	3.5	7.6	12.3	10.4
		Partly slatted floor, pit, >1 month	7.1	1.4	10.4	2.7	4.8	5.3	6.2
		Solid floor manure channel	21.5	7.0	19.4	6.8	10.4	14.4	25.2
Emission reducing		Flushing manure channel (gutter) *ER = 40	3.3	N/A	4.3	2.9	1.8	2.5	3.9
		(Group) housing with feeding stalls and manure pit with slanted walls *ER = 45	1.9	N/A	1.8	N/A	N/A	N/A	N/A
		Water and manure channel (fully slatted floor) *ER = 50	N/A	1.8	0.7	N/A	N/A	N/A	N/A
		Manure pan underneath *ER = 65	N/A	3.1	1.3	N/A	N/A	N/A	N/A
		Frequent manure removal with vacuum system *ER = 25	N/A	N/A	N/A	0.4	0.6	N/A	N/A
		Partially slatted floor with water and manure channel *ER = 40	N/A	N/A	N/A	0.7	4.2	4.1	1.0

n = 83;
* ER = Emission reduction (%)
source: own composition, based on UNECE guidance
Emission reference system: fully slatted pig houses with a storage pit underneath
(additional specific reference techniques have been identified for different pig age groups based on UNECE Guidance; Bittman et al. 2014, Pig age groups were named based on the Hungarian National Inventory report)

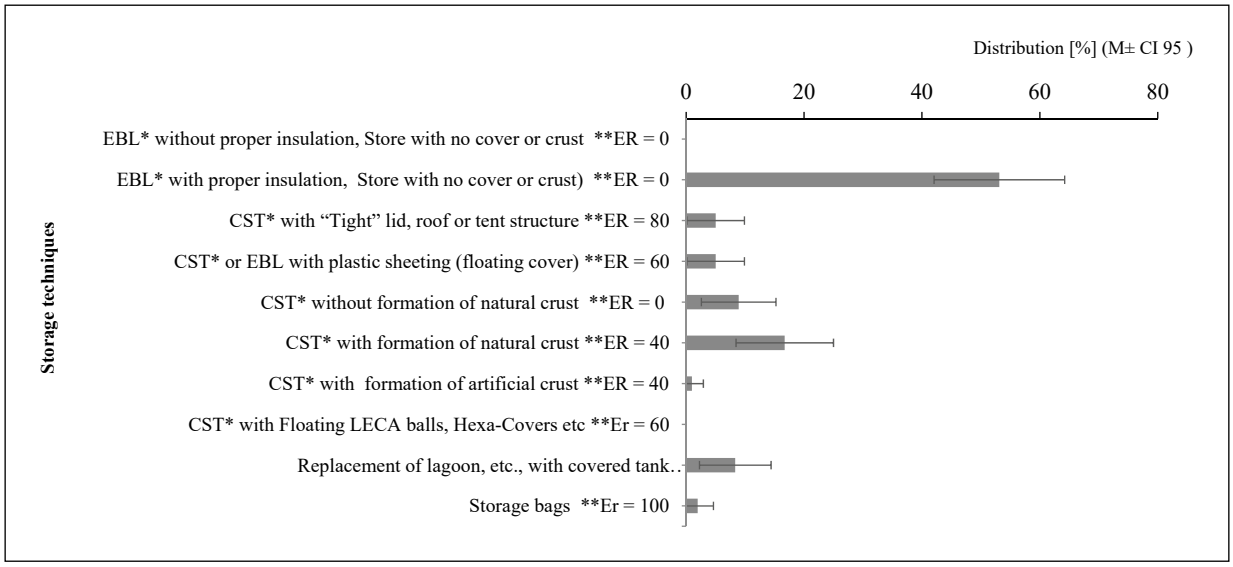
difference between different storage techniques χ 2 ([9]; N = [81] = 185.782; p < .001. Follow-up for Friedman test, Wilcoxon tests were performed. The most common solution was found to be the store with no cover or crust followed by allowing formation of natural crust, which has a significantly lower prevalence (T = 120; Z = -3.689; p <.001 (2-tailed); r = .409). Similarly, it gave a significantly lower prevalence of the comparing allowing formation of natural crust with the plastic sheeting (T = 44; Z = -2.246; p < .025 (2-tailed); r = .249) and with the storage bag (T = 16.5; Z = -3.181; p < .001; (2-tailed); r = .353).

The biological methods were of highest proportion with 36.86% among manure treatment options followed by anaerobic and aerobic digestion technologies in a much smaller but still measurable proportion, with a value of around 5%. In addition to this, 10% of the solid manure was subjected to anaerobic fermentation and 2% into an aerobic system.

Field application

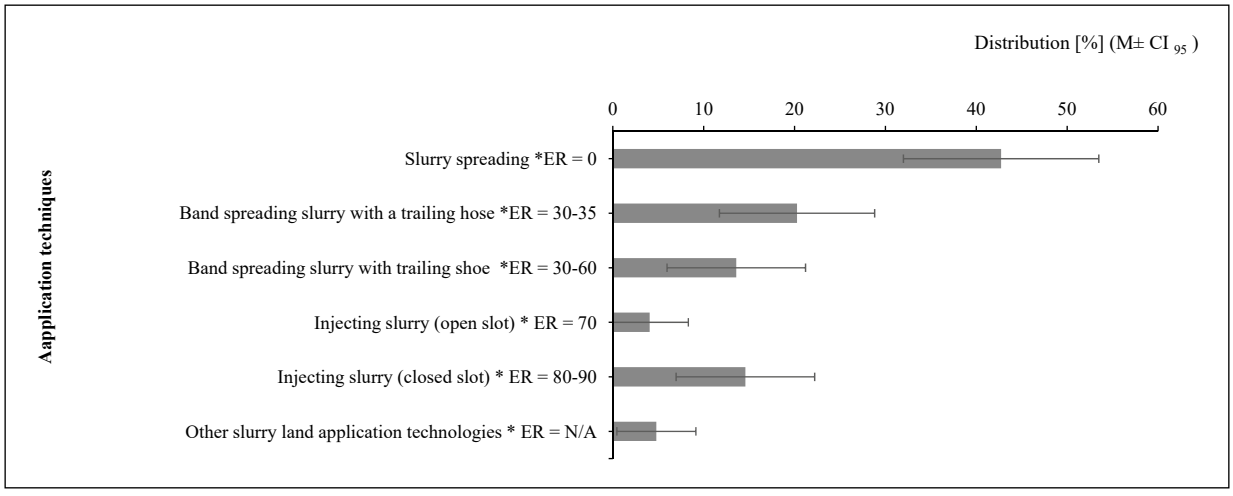
Figure 3 summarizes the distribution of the slurry application solutions.

Our study showed that spreading was used for the largest proportion (42.72%). The so-called other categories (e.g., flooding, poplar and hose reel irrigation) represent 4.8%, allowing selecting others in complex categorization cases. Using the Friedman test we found significant differences between the individual technologies χ2 ([5]; N = [81] = 49.762; p <.001. As the Friedman test was significant, the



n= 84; using the Wilson Binomial Confidence Interval
* EBL = Earth-banked lagoon; CST = Partially or fully above-ground concrete/steel tank
**ER = emission reducing (%)
reference technique: store with no cover or crust

Fig. 2. Ammonia emission abatement measures for pig slurry storage



n=90; using the Wilson Binomial Confidence Interval
* ER = Emission reduction (%)
reference technique: spread over the whole soil surface ("broadcast") and not followed by incorporation, and not targeting application timing conditions that minimise NH_3 loss.

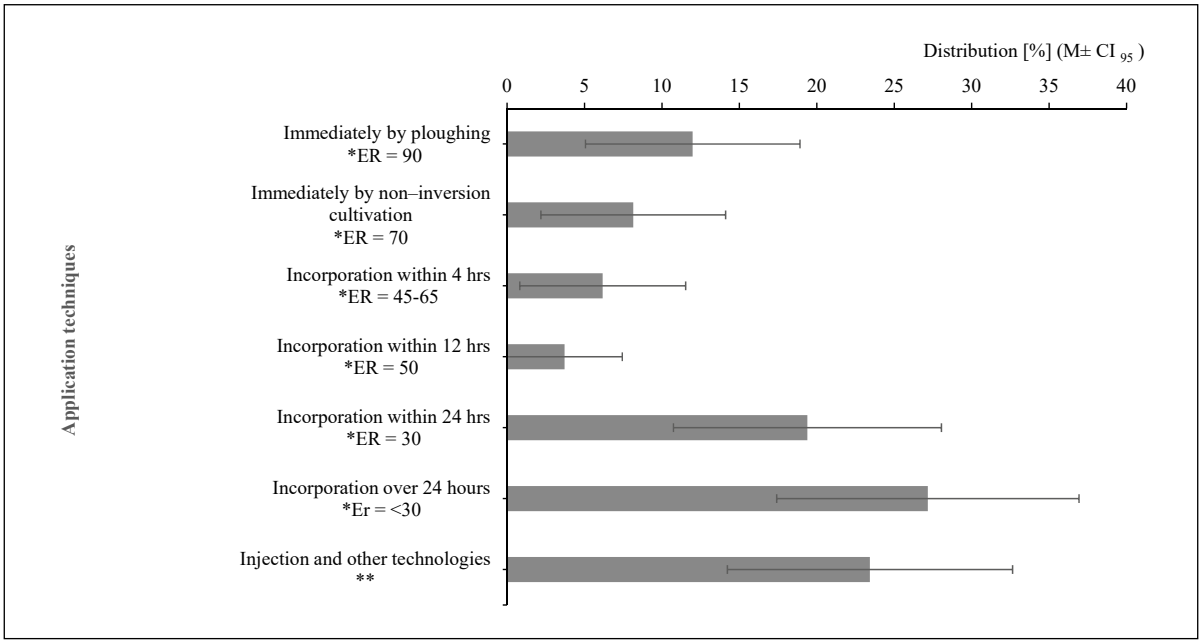
Fig. 3. Distribution of the field application technologies for slurry utilization

Wilcoxon test was used as a follow-up test to determine which application groups are different. The use of slurry spreading was significantly more frequent than the second most common solution, the band spreading with trailing hose, T = 428; Z = -2.589; p = 0.01 (2 tailed); r = .287. Another significant difference was found between the trailing hose and the other techniques T = 51; Z = -2.954; p < 0.01 (2 tailed); r = .328. The UNECE Guidance only recognises the application category within 24 hours. However, in our research, slurry incorporation beyond 24 hours predominates (27.1%) therefore, this category was also included in Figure 4.

In the case of solid manure (Fig. 5), immediately by ploughing with a value of 42.3 % was found in the first place among field application technologies, followed by undesirable incorporation within 24 hours.

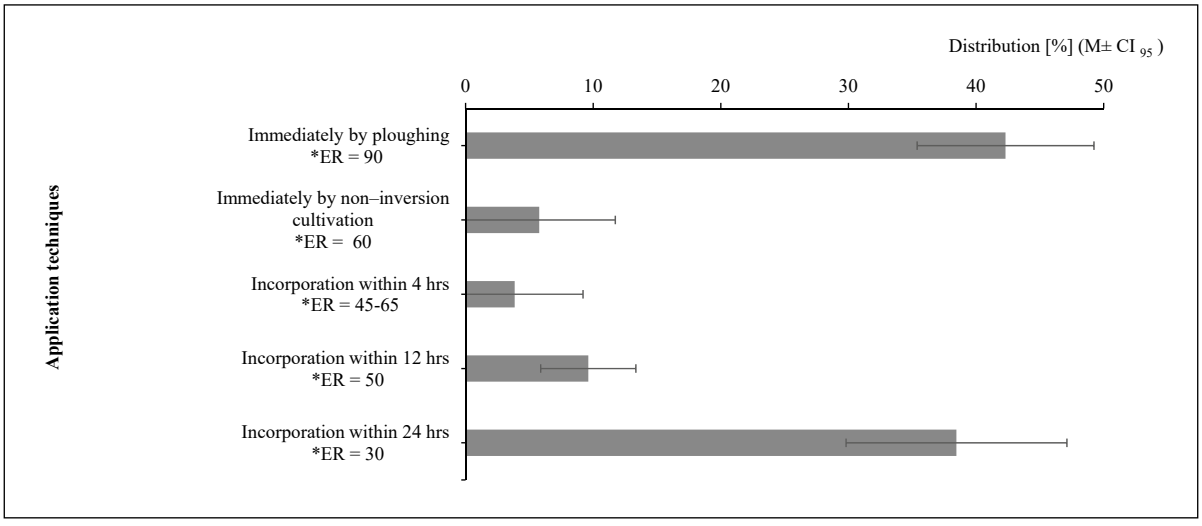
Discussion

The purpose of this work was to assess the prevalence of manure treatment techniques available to reduce ammonia emissions in pig farms in order to meet increasingly stringent environmental standards. The results suggest that none of



n = 88; using the Wilson Binomial Confidence Interval
* ER = emission reduction (%) ** N/A
reference technique: spread over the whole soil surface ("broadcast") and not followed by incorporation, and not targeting application timing conditions that minimise NH_3 loss.

Fig. 4. Distribution of the abatement techniques for slurry application to land



n = 52; using the Wilson Binomial Confidence Interval
* ER = emission reduction (%)
reference technique: spread over the whole soil surface ("broadcast") and not followed by incorporation, and not targeting application timing conditions that minimise NH_3 loss.

Fig. 5. Distribution of the abatement techniques for solid manure application to land

the farm technologies extensively uses ammonia reduction solutions. Significant developments are needed along the whole manure chain (in pig housing, manure storage and treatment and in field application) to reduce ammonia emissions more and more completely.

In pig housing technologies, the data suggest that domestic littering solutions are present in a higher proportion (with an average of 13.3% for each pig category) than in many Western European countries. For example, straw-based systems represent less than 8% of French pig farmers, and more than 91% have fully or partly slatted floors in pig pens (Ifip 2010). In our study, we could not prove the latter statement with the conditions in Hungary, where the solid floor manure channel also represents a significant proportion. Corresponding to Bittman et al. (2014), primarily such emission reducing housing systems in combination with storage solutions have typically been implemented on larger farms (IPPCs) up to now. Many ammonia reduction techniques may only be implemented in newly built livestock buildings, which is connected to the cost of implementation.

The results for manure storage were similar to the BAT document (Santonja et al. 2017) due to the lack of manure coverage in Hungary, as only a few EU member countries (e.g., the Netherlands, Denmark) cover slurry storage facilities with tents or roofs so far. All studied farms for the research had manure storage facilities with insulation in accordance with legal requirements. However, from the emission side, solutions without cover or crust were dominant. In some countries, the distribution of techniques may be hindered, as stated by Newell Price et al. (2011) within the DEFRA project, as 80% of cattle slurry storages already have natural crust on the surface. Loyon (2018) made a similar finding in his scientific work, mentioning the lack of cover for manure storage to animal husbandry in France.

Concerning manure processing, in a previous European study (Foged et al. 2011), anaerobic digestion was the most used animal manure processing solution. This statement could not be verified only by examining the domestic conditions of pig manure management in Hungary due to the complex nature of fermentation substrates. It can be said that there is still much untapped potential in biogas production, what is more, specific manure and other raw material databases are lacking in many European countries, but some studies have recently addressed the issue for Central Eastern Europe (Kozlowski et al. 2019, Soha et al. 2021).

In the case of field application, our study supports the findings of the NAPCP document on the prevalence of technologies. Slurry application technology is predominantly the spreading method (45%), followed by band (37%) and then injection (14%) of which the share of open injection is only around 1%. Unfortunately, the most common use of the most outdated spreading technology has the highest ammonia release. However, it should be noted that not only Hungary is lagging in this respect, the lack of more advanced application technologies can also be observed in France (Loyon 2018). In recent years, significant progress has been made in Hungarian agriculture with the band spreading and closed shot injectors, but further measures to reduce the spreading method must be supported (Péterfalvi et al. 2017). Previous studies (Newell Price et al. 2011, Bittman et al. 2014) have found that the achievement of results hampers by the cost of purchasing and maintaining new machinery. On the other hand, this may be partially offset by increasing nitrogen concentrations of manure and agronomic benefits. Regarding the field application time, the existence of the expected immediate incorporation did not dominate, which would be most favorable in terms of ammonia emissions and nutrient loss (Bittman et al. 2014). The current Hungarian rules prescribe the same requirement for immediate incorporation (Decree No. 59/2008). Our results also partially contradict the BAT document, as they allow for the extension of the incorporation time in certain unfavorable circumstances, but only 12 hours after application. It should be emphasized that there is a particular need to address the shortening of the time between application and incorporation, as Jarosz and Faber (2020) identified as one of the most effective NH_3 emission reduction options for achieving the 2030 ammonia emission targets in Poland, which can also be followed for Hungary.

The study results should be viewed with some limitations. We have not examined the effect of feeding on ammonia emissions as this is not a technical intervention. Significant results can also be achieved using feed supplements, with 44% of the 520 Polish farms surveyed using them, according to Piwowar's (2020) analysis. In addition, more attention should have been paid to intensive pig farms, as they account for a substantial proportion of domestic pig production and are at the forefront of applying best practice examples.

To briefly summarize, despite the emission reduction methods and technologies, their prevalence was significant only where legislation had forced their application. However, this is not only a typical situation of Hungarian agriculture because our findings are also reflected in other countries in the region, such as Poland (Piwowar 2020).

Conclusion

Livestock farming and related manure management have to deal with a number of environmental problems, in addition to increasingly stringent regulations. A sophisticated environmental approach has been highlighted, for all elements of manure technology should conjointly minimize contamination of surface and groundwater, soil, and air. This research aimed to examine the prevalence of technologies that reduce ammonia emissions in Hungarian pig farming facilitating compliance with national emission standards. The survey and statistical analysis showed that advanced ammonia emission reduction techniques for pig housing, external manure storage cover, manure processing, and field application are not yet widespread. Compliance with specific environmental measures has been implemented differently (e.g., the Nitrates Directive has a high compliance level). It is essential to provide more information about these results influencing the environment, applicability of each intervention, and their benefits in education and training. It is important to be aware of the mechanisms that control the loss of manure N and the practices that can be performed at each level of manure management to minimize losses. The research and the literature analysis highlighted that in Hungary, Central Eastern Europe, and even some Western European countries, further developments are needed in proper manure management related to livestock farming. When implementing measures

to promote the growth of the domestic pig sector, it is also essential to analyze gaseous emissions, supplemented by other benefits obtained by applying good agricultural practices.

Further investigation of these procedures is also recommended for other emission factors for proper overall effect. Generally, research should not focus only on reducing a single pollutant with a whole chain approach because of emission interactions. The extension of the present research work is possible by a similar survey to be carried out for other farm animal species (cattle, poultry), and the correlations of greenhouse gas emissions should be examined together with ammonia emissions.

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