Original Paper

Pilot study on farming practices of Simmental dairy farms in Slovakia

Ondrej Pastierik*, Miroslav Záhradník, Andrea Mrekajová, Ján Huba

National Agricultural and Food Centre, Animal Production Research Institute for Animal Production Centre Nitra, Slovak Republic

Article Details: Received: 2022-12-22 | Accepted: 2023-06-20 | Available online: 2023-09-30

https://doi.org/10.15414/afz.2023.26.03.236-242

The pilot survey among 36 Simmental cattle breeders in Slovakia was performed by an expert visiting farms and filling a questionnaire with farm managers. Data on the factors that influence the emission factors of ammonia, methane or nitrous oxide are needed to provide support for sustainable livestock production policies. Highest milk production (8,305 ±828 kg) was found in the group with intensive production system comprising 7,078 cows. Extensive systems were represented by only 2 farms with 451 cows producing 5,527 ±1,094 kg of milk. All farms used phase feeding, only 15% of all cows in the survey were grazing. The dominant way of handling animal waste was solid manure with straw bedding (30 farms), while slurry prevailed for the remaining farms. There were 8 farms (2,095 cows) equipped with surface covered tanks, bags or using natural crust to reduce emission from slurry storage. Median emission factors of a dairy cow based on survey data were 137.2 kg, 0.850 kg and 50.8 kg per year for methane, nitrous oxide and ammonia, respectively. When aggregated by manure management, cows producing solid manure had a lower emission factor for methane but higher for ammonia and nitrous oxide compared to cows under liquid manure management. Linking data from various aspects of dairy production at farm level supports holistic approach as important for evaluation of food systems in the future.

Keywords: farming practices, GHG, ammonia, Simmental

1 Introduction

The capacity to produce proteins rich in essential amino acids out of fibrous carbohydrates is an important asset of ruminants to optimize biomass sources in agricultural production. There is a growing social and environmental incentive to reduce the waste of nutrients in the carbon and nitrogen cycles of farms (Setoguchi et al., 2022). Major causes of variation in emission factors include a lack of accurate data on management of animal waste and the excretion of nutrients (Oenema et al., 2005). Uncertainties in the emission estimates can be solved by gathering information from a representative number of animal head counts falling under specific management conditions (Brouček, 2015).

Within the age structure of an animal herd, the category of dairy cows contributes the most to the amount of emissions produced, primarily due to their higher live mass and fully developed digestive systems. However, there is a lack of data on the specific emission factors for the Simmental breed on ammonia and nitrous oxide. Methane emission intensity of Simmental cows was 25 g.kg DMI^{-1} (dry matter intake) producing 6,300 kg of milk in experiment of Münger and Kreuzer (2008). The review of Liu et al. (2017) reported that ammonia emissions varied widely due to the differences in the manure management systems. Emissions of nitrous oxide are low compared to methane but storage practices and their effect on nitrogen oxidation downstream of the nutrient flow in the production process have to be considered (Brouček, 2017).

Ongoing farming practices and emission profiles of farms breeding Simmental cattle are little explored. However, these represent an important portion of dairy cattle in Slovakia and their management decisions will have some effect on the environment. The objective of the present study was to survey Simmental dairy farms on the factors that influence the emissions of ammonia, methane or nitrous oxide per cow of this breed in Slovakia.

***Corresponding Author:** Ondrej Pastierik, National Agricultural and Food Centre, Animal Production Research Institute for Animal Production Centre Nitra, Hlohovecká 2, 951 41, Lužianky, Slovak Republic, ondrej.pastierik@nppc.sk https://nppc.sk

2 Material and methods

2.1 Farm survey

A pilot study based on a survey was developed to gain information regarding the most important aspects of dairy operation. It included 41 questions on animal counts, manure management, performance and reproduction parameters for the livestock category of production cows. In addition to that, questions were compiled to inquire about feeding, housing, manure or slurry storage, application and processing. All questions were within the scope of the Code of good agricultural practice to reduce ammonia emissions from livestock farming and application of fertilizers to soil (MŽP SR, 2020), referred to as the Code in this article for the purpose of clarity and brevity. During the year 2021, questionnaire was filled out by an expert from the Association of Slovak Spotted Cattle Breeders – Cooperative at the site with the assistance of local farm manager. A total of 36 farms with Simmental cattle breeding pure or crossbreds were selected according to previous experience with providing reliable data. Farms were distributed across Slovakia, mainly in the uphill regions with prevailing temperate climate. Three levels of intensity (intensive, semi-intensive, extensive) to characterize milk production were used according to Huba et al. (2016). However, the proportions of specific systems within the surveyed group of all farms were not intended to be a representative sample of all systems that utilize the Simmental breed or produce milk in Slovakia.

2.2 Calculations

Knowledge about conversion of energy and utilization of nitrogen in ruminants was fundamental for calculating emissions of GHG and ammonia according to the guidelines from the Intergovernmental Panel on Climate Change (IPCC, 2006). Gross energy (GE) was derived based on the live body weight, net energy estimates required for maintenance (Equation 10.3), animal activity (Equations 10.4 and 10.5), lactation (Equation 10.8) and pregnancy (Equation 10.13) of cattle as identified in IPCC (2006) as well as equation of Gibbs and Johnson (1993) to calculate ratio of net energy available in a diet for maintenance to digestible energy consumed. In this way, GE represented total amount of energy which cow had to intake in order to satisfy different types of requirements for net energy mentioned above. The value for digestible energy consumed was calculated as the percentage of GE. Experiential relationship (V. Brestenský, personal communication, October 5th, 2022) to fix the positive or negative change in digestibility coefficient by 0.001% added to default value 70% for each kg of milk which results as the difference between actual quantity of production and the value 6,000 kg per year and cow was used in order to describe rate of nutrients available from feed in link to milk production:

$$\textit{digestibility coefficient}\ \% = 70 + (\textit{milk production} - 6{,}000) \times 0{,}001$$

where: digestibility is the proportion of energy digested from the GE intake; milk production is the average amount of milk produced by a dairy cow per year at a farm

Dry matter intake was derived as the GE intake divided by factor 18.45 $MJ.kg^{-1}$ of feed (IPCC, 2006). Methane emission factor of a dairy cow was the sum of the methane emitted from two sources by enteric fermentation and manure management over the timeframe of a year. Manure management refers to the source of methane related to manure or slurry handling, processing and storage.

The total amount of nitrogen intake was derived from crude protein (CP) requirements (Petrikovič & Sommer, 2002) for milk production. Nitrogen excreted (Nex) at housing or pasture constituted a mass from which nitrogen losses were deducted at each stage downstream of the nutrient flow in the production cycle up to the application in soil. Default factors of EMEP/EEA air pollutant emission inventory Guidebook (EEA, 2019) were used to quantify Nex converted to ammoniacal nitrogen (NH_3-N) at the housing, storage and application. Direct emissions of N_2O from manure management were calculated using Tier 2 approach in which default factors 0.005 kg and 0.01 N_2O-N Nex-1 for slurry or manure removed from housing daily and deep bedding, respectively (IPCC, 2006; Sommer et al., 2000).

3 Results and discussion

A pilot survey was conducted to identify the characteristics of milk production systems, current technologies and practices at dairy farms breeding Simmental cattle in relation to emissions of GHG and ammonia. In Table 1 is shown differentiation of milk production systems into three levels of intensity reflecting on economical and technology indicators.

Factors considered in differentiation were connected to the economic optimization of livestock production systems conducted by the Research Institute for Animal Production Nitra (Huba et al., 2016).

3.1 Production profile

Intensive production systems account for more than 50% of the total dairy cows´ numbers, while the number of extensive production system is only marginal in this

Table 1 Dairy production systems in Slovakia

Indicator	Level of intensity		
	intensive	extensive	semi-intensive
Cost per feeding day	>7 €	<4 €	5–6 €
Herd size (dairy cows)	>200	1–100	<200
Geographical location	southern low lands	mountainous and foothill areas	uplands and foothills
Feeding management	all-year round silage based TMR	dairy cows and heifer on seasonal pastures with minimum concentrate feed	heifer on seasonal pastures (for dairy cows additional only)
Management target	20 kg lifetime daily yield	long productive life-span, healthy cows, with good locomotion	various combinations
Technology level	high level of innovation	low cost technology	various combinations
Prevailing breed	holstein	Pinzgau, Simmental-Fleckvieh	various cross-breds
Milk sale – processing	industry	own processing, direct sale	various combinations

Adopted from Huba et al. (2016)

Table 2 Number of cows and total milk production by production system

Intensity of farming	Farms	Number of dairy cows				Milk* ±SD	min	max
		cows	mean ±SD	min	max			
Intensive	22	7,078	322 ±98	110	500	8,305 ±828	7,005	9,933
Semi-intensive	12	3,483	290 ±86	180	425	7,194 ±622	6,297	8,204
Extensive	2	451	226 ±134	131	320	5,527 ±1,094	4,753	6,300

*mean milk production in kg per cow and year

context. Approximately 40% of dairy cows belong to semi-intensive production systems, which combine the characteristics of intensive and extensive production systems (Gibon, 2003). Survey dataset included 11,012 cows in the study, which represented approximately 31% of the total Simmental population in the national milk recording scheme in 2021. Distribution of dairy cows was biased towards intensive systems and fits the description of marginal occurrence of the extensive production systems. Intensive farms had the highest head count, but variability was lower for the group of semi-intensive farms. Only a small number of cows were kept on farms with an extensive system compared to farms with an intensive system.

There was a quantified increase of milk production of farms classified in the higher intensity system (Table 2). The intensive systems have a larger herd size, higher milk production and milk sales prices (Pavlík et al., 2015) but higher costs per feed day as well (Akbay & Akdoğan, 2022). The farm size in the study of Akbay & Akdoğan (2022) was much smaller and milk production per day was lower (22.5 kg) for the group of farms with the largest herd size than in our dataset.

The group of intensive farms had a higher average milk performance per dairy cow than the national average (8,037 kg) for milk production in 2021 (ŠÚ SR, 2021). The results included in the milk recording scheme (PS SR, 2021) shown a slightly lower average daily milk production (23.0 kg) kg of cows in all lactation than cows in the intensive system (23.7 kg) in our results. Increased productivity and feed efficiency was identified as the greatest opportunity for mitigating ammonia and methane emissions per unit of livestock product (Liu et al., 2017).

3.2 *Technologies and practices*

3.2.1 Feeding

All farms used phase feeding, while 10 farms utilized grazing of cows. The portion of cows that were grazed was 15% out of all cows in the survey. Despite the scale of the techniques that have been examined, only 3 farms were recorded to practice strip grazing. Therefore, it may be assumed that other farms (7; count) provide pasture for a limited period of the day in the proximity of the milking facility. Controlled grazing of livestock often leads to the intake of higher quality forage compared to free-range grazing. Both techniques can provide ecosystem services in the form of supporting carbon soil sequestration when adjusted for appropriate stocking rate management (Rouquette et al., 2016). Jebari et al. (2022) determined that at least 0.4 $LU.ha^{-1}$ is needed for net GHG emissions per livestock unit (LU) to be reduced and threshold of 0.95 $LU.ha^{-1}$ bellow which no soil organic carbon accumulation occurs in the conditions of Northern Spain. Although there were no records on the extent of the grazing area in our dataset, it can be assumed that the dairy cow herds can contribute to the cycling of nutrients in the areas around the farms subjected to the condition of good grazing management. In addition, No increased time for grazing of dairy cows during the day was found.

3.2.2 Manure management

In total, excretions from 9771 cows (88.7% of the total number of cows) were managed as manure, including manure that comes from housing of dry or high pregnant cows as well. The rest of the excretions were managed in systems with prevailing slurry production at 5 farms. Table 3 gives the information about the manure management systems and their proportions within the total number of dairy cows in the dataset. The prevailing management system was solid manure incorporating straw bedding. A small proportion of cows in our survey was included in slurry excretion management, but 65% (1129; count) were housed with bedding from solids after separation of the anaerobic digestate. Biogas production is attributed to a reduction in organic matter in the digestate through fermentation and solid-liquid separation while energy is generated. An extensive life cycle analysis of dairy production system of Setoguchi et al. (2022) revealed that implementation of a biogas plant producing recycled bedding material reduced GHG emissions by 6.8% when compared with conventional slurry treatment.

Methane and nitrous oxide emissions are negligible at the stage of housing. Ammonia emissions in housing can be reduced by floor type to influence micro-conditions of manure storage by quick separation of liquid fraction (Schmithausen et al., 2018). Hou et al. (2015) concluded based on 11 farm-scale studies that slatted-floor and deep litter stables had significantly lower NH_3 emissions than solid floor stables. The most widespread housing mitigation practices among farms in our dataset were slated floor with scraping shovels (9; count) and air ventilation of stalls (22; count) which were present for 24.1% and 66.0% of all cows, respectively. Combination of both practices occurred on 7 farms (2125 cows), representing 19.3% of all cows in the survey.

Storage of solid manure was mostly based on cows' excretions mixed with straw on heaps, usually uncovered, located on hardened surfaces designed against leaching. There were 8 farms using the techniques listed in the Code as mitigating ammonia emissions indicated in Table 4. The number of cows falling under one of these techniques constituted 19% out of the total in our dataset.

Manure was spread over the field followed by incorporation into the soil within 12 hours. A minor fraction of cows' excretions managed as slurry was applied by a band spreading trailing hose (270 cows), shallow injection with open (748 cows) or closed slot (223 cows). Direct N_2O are increased with injection but reduce NH_3 emissions as well as indirect N_2O from NH_3. Neutral net effect on GHG emission can be reached with injection techniques despite the expected increase of fossil fuel consumption (Aguirre-Villegas & Larson, 2017).

Table 3 Proportion of manure and bedding material by manure management system

Type	Farms	Proportion of manure** ±SD	Bedding materials	Farms	Cows
Manure	30	1.00 ±0.00	straw	29	9,147
			sawdust	1	131
Manure and slurry combinations	1	0.67 ±0.00	straw	2	605
	1	0.18 ±0.00			
	4	0.19 ±0.02	solids*	4	1,129

* solids after separation from liquid fraction; ** mean proportion of the total number of cows, the excretions of which is managed as manure. The sum of manure and slurry proportions equals 1.00 – total amount of excrements; SD – standard deviation of the mean

Table 4 Mitigation techniques used for storage of slurry

Technique	Farms	Cow number	
		cows	proportion of total
Surface covered, tank, vessel	3	783	0.07
Storage bags	1	310	0.03
Natural crust	4	1,002	0.09

3.2.3 Emission factors

The median emissions factors of dairy cows presented in Figure 1 were 137.2 kg, 0.850 kg and 50.8 kg for year for methane, nitrous oxide and ammonia, respectively.

The calculated dry matter intake required for milk production in ratio with methane represented 23.5 g CH_4.kg DMI^{-1}, which is higher than range 19.0–20.2 CH_4.kg DMI^{-1} found in experiment of De Boever et al. (2017) focused on the digestibility differences between silage maize varieties. The digestibility of feed dry matter is given by interaction of passage rate through rumen, proportion of concentrate and feeding level (INRA, 2018).

However, we added 0.001% of digestibility point to basic level 70% for each kilogram of milk above 6000 kg of milk per dairy cow and year. In this way, we reflected the effect of higher availability of energy with increasing milk production in our model. As shown in Table 5, enteric fermentation represented a substantial part of the total methane produced by cows in agreement with (Brouček, 2015; Mathot et al., 2012). Solid manure provides unfavorable conditions to methanogenic bacteria compared to slurry, which is taken into account by the guideline (IPCC, 2006) using methane conversion factor with consideration for outside temperature.

The aggregations by manure management in Table 6 described large differences in emissions between slurry and manure. Farms where slurry is the dominant form of manure management had higher methane EF but lower ammonia and nitrous oxide EF. According to the survey data of Aguirre-Villegas & Larson (2017), liquid manure storage contributed to GHG emissions the most out of the manure management types found in the Wisconsin area, although emissions could be reduced more readily using processing techniques if the scale was feasible.

Excreted ammoniacal N presents the pool from which losses occur due to leachate, absorption to bedding material or volatilization (EEA, 2019). The crude protein intake was calculated based on the protein requirement for milk production (Petrikovič & Sommer, 2002). Considering this fact reduces the variability in the amount of excessive CP intake by grazing, because number of grazing animals is low. This highlights phase feeding and feed ration optimization potential to optimize production while the management of age groups and nutrients balance can be achieved with higher precision for cows in housing. On the other hand, underestimation of excreted nitrogen could take place for low producing cows, which were mainly in the extensive production system characterized by utilization of grazing in our conditions. Under practical conditions, nitrogen in feed is converted to milk proteins with 20–35% efficiency. Remaining nitrogen is excreted outside in on the pasture or inside housing (Oenema et al., 2005). Liu et al. (2017) found that average ammoniacal N loss as a percentage of N intake for dairy barns with mechanical ventilation was lower than that for dairy barns with natural ventilation.

Emissions of nitrous oxide were much lower for slurry-based manure management systems than for solid manure (Table 6). The low value of nitrous oxide for slurry was caused by the fact that a single farm reported no crust formation in liquid manure storage and thus eliminating N_2O emissions. Porous materials promoting aerobic conditions initiate N_2O formation followed by

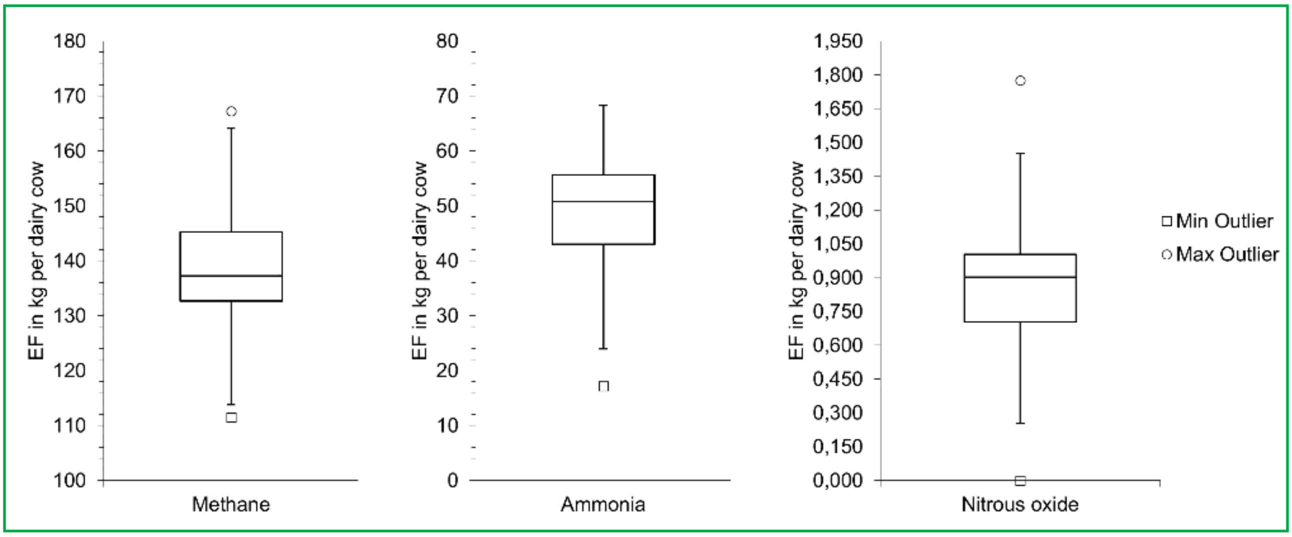

Figure 1 The ends of the whisker are set at 1.5 times interquartile range (IQR) above the third quartile and 1.5*IQR below the first quartile (Q1)
tIf the minimum or maximum values are outside this range, then they are shown as outliers

Table 5 Means ±standard deviation, 25th and 75th percentiles of calculated parameters to determine emission factors

Parameter		
Dry matter intake (kg DM.day^{-1})	mean ±SD	16.0 ±1.08
	Q1	15.6
	Q3	16.5
Gross energy (MJ kg.day^{-1})	mean ±SD	305.1 ±20.8
	Q1	293.7
	Q3	315.6
Crude protein intake (CP % of DMI.day^{-1})	mean ±SD	15.2 ±0.8
	Q1	14.6
	Q3	15.7
Nex (nitrogen g.cow^{-1}.day^{-1})	mean ±SD	305.1 ±20.82
	Q1	264.8
	Q3	302.5
Enteric fermentation (kg CH_4.year^{-1})	mean ±SD	130.1 ±8.9
	Q1	125.2
	Q3	134.6
Manure management (kg CH_4.year^{-1})	mean ±SD	8.6 ±7.15
	Q1	5.6
	Q3	6.0

DM – dry matter; SD – standard deviation of the mean; MJ – mega joules; CP – crude protein content as the percentage of dry matter intake (DMI); Nex – nitrogen excreted by cow per day; Q1 – upper threshold of 25th percentile; Q3 – lower threshold of 75th percentile; CH_4 – methane

Table 6 Mean emission factors by manure management

Type	Farms	Methane			Ammonia			Nitrous oxide		
	n	mean ±SD	min	max	mean ±SD	min	max	mean ±SD	min	max
		kg CH_4.year^{-1}.cow^{-1}			kg NH_3-N year^{-1}.cow^{-1}			kg N_2O year^{-1}.cow^{-1}		
Manure	30	135.7 ±9.6	111.5	156.2	51.9 ±8.7	27.6	68.3	0.956 ±0.3	0.53	1.9
Slurry and manure combinations	6	153.4 ±8.3	145.1	167.2	23.6 ±9.5	17.1	42.3	0.224 ±0.1	0.00	0.4

CH_4 – methane; NH_3-N – ammoniacal nitrogen; N_2O – nitrous oxide

denitrification processes in soil. As a result, solid manure is assumed to have higher potential N_2O emissions than slurry with no crust (IPCC, 2006).

4 Conclusions

Milk production utilizing the Simmental breed is driven by efficiency as most farms with intensive production system do not fall behind the national average milk performance. Despite the national strategies to support extensive farming systems, Simmental farms graze a limited number of cows. Solid manure production took place on most farms, resulting in lower estimates for methane from manure management than for farms using slurry. For the future collection of information is needed to include questions about extent of land used for forage production, manure application or proportion of concentrate in feed ration.

Acknowledgments

Work on this publication was supported by APVV-19-0544, APVV-18-0121 and Operation programme no. 313011W112.

References

Aguirre-Villegas H. A., & Larson R. A. (2017). Evaluating greenhouse gas emissions from dairy manure management practices using survey data and lifecycle tools. *Journal of Cleaner Production*, 143, 169–179.

Akbay, C., & Akdoğan, F. (2022). Economic Analysis of Dairy Cattle Farms in Izmir Province of Turkey. *Kahramanmaraş Sütçü İmam Üniversitesi Tarım ve Doğa Dergisi*, 25(3), 598–605.

Brouček, J. (2015). Methane yield from cattle. sheep. and goats housing with emphasis on emission factors: a review. *Slovak Journal of Animal Science*, 48(3), 122–139.

Brouček, J. (2017). Nitrous oxide production from cattle and swine manure. *Journal of Animal Behaviour and Biometeorology*, 5, 13–19.

De Boever, J. L., Goossens, K., Peiren, N., Swanckaert, J., Ampe, B., Reheul, D., De Brabander D. L., De Campeneere, S., & Vandaele, L. (2017). The effect of maize silage type on the performances and methane emission of dairy cattle. *Journal of animal physiology and animal nutrition*, 101(5), 246–256.

European Environment Agency (EEA). (2019). *EMEP/EEA air pollutant emission inventory Guidebok 2019 – EAA Report*. Publications Office of the European Union, 13. https://www.eea.europa.eu/publications/emep-eea-guidebook-2019/part-b-sectoral-guidance-chapters/4-agriculture/3-b-manure-management/at_download/file

Gibbs, M.J., & Johnson, D.E. (1993). "Livestock Emissions." In *International Methane Emissions, US Environmental Protection Agency*, Climate Change Division, Washington, D.C., U.S.A.

Gibon, A., & Mihina, S. (2003). *Livestock Farming Systems in Central and Eastern Europe*. EAAP Technical S. Wageningen Academic Publishers.
https://lib.ugent.be/catalog/ebk01:2550000000001263.

Hou, Y., Velthof, G. L., & Oenema, O. (2015). Mitigation of ammonia. nitrous oxide and methane emissions from manure management chains: a meta-analysis and integrated assessment. *Global Change Biology*, 21(3), 1293–312

Huba, J. et al. (2016). Udržateľné systémy chovu. Situačná správa o plnení rezortného projektu výskumu a vývoja (RPVV – VÚŽV 1). NPPC – VÚŽV.

INRA, Noziere, P., Sauvant, D., & Delaby, L. (2018). *INRA feeding system for ruminants*. Wageningen Academic Publishers.

The Intergovernmental Panel on Climate Change – IPCC. Chapter 10. *Emissions From Livestock and Manure Management. Guidelines for National Greenhouse Inventories 4*, Agriculture, Forestry and Other Land Use. National Greenhouse Gas Inventories Programme. IGES.

Jebari, A., Álvaro-Fuentes, J., Pardo. G., Batalla, I., Rodriquez Martin, J. A., & Del Pardo, A. (2022). Effect of dairy cattle production systems on sustaining soil organic carbon storage in grasslands of northern Spain. *Regional Environmental Change*, 22, 67.

Liu, Z. Liu, Y., Murphy, J. P., & Maghirang, R. (2017). Ammonia and Methane Emission Factors from Cattle Operations Expressed as Losses of Dietary Nutrients or Energy. *Agriculture*, 7(3), 16.

Mathot, M., Decruyenaere, V., Stilmant, D., & Lambert, R. (2012). Effect of cattle diet and manure storage conditions on carbon dioxide. methane and nitrous oxide emissions from tie-s tall barns and stored solid manure. *Agriculture, Ecosystems & Environment*,148, 134–144.

Münger, A., & Kreuzer, M. (2008). Absence of persistent methane emission differences in three breedsof dairy cows. *Australian Journal of Experimental Agriculture*, 48, 77–82.

Kódex správnej poľnohospodárskej praxe na znižovanie emisií amoniaku z chovov hospodárskych zvierat a aplikovania hnojív do pôdy. (2020). MŽP SR. https://www.minzp.sk/files/oblasti/ovzdusie/ochrana-ovzdusia/metodicke-postupy-prirucky/kodex_spravnej_polnohosp_praxe_final.pdf

Oenema, O., & Tamminga, S. (2005). Nitrogen in global animal production and management options for improving nitrogen use efficiency. Science in China. Series C. *Life sciences/Chinese Academy of Sciences*, 48(2), 871–87.

Pavlík, I., Huba, J., Peškovičová, D., Záhradník M., & Mihina, S. (2015). Dairy farm size in relation to performance and economic efficiency measures. *EAAP – 66th Annual Meeting of the European Federation of Animal Science* – Book of Abstracts No. 21, Wageningen Academic Publishers (204 p.).

Petrikovič, P., & Sommer, A. (2002). *Potreba živín pre hovädzí dobytok*. 2nd ed., VÚŽV.

Rouquette, F. M. (2016). Invited Review : The roles of forage management, forage quality, and forage allowance in grazing research. *The Professional Animal Scientist*, 32(1), 10–18.
https://doi.org/10.15232/pas.2015-01408

Výsledky kontroly úžitkovosti hovädzieho dobytka v Slovenskej republike za rok 2021. (2021). PS SR. http://test.plis.sk/volne/rocenkamagazin/rocenka.aspx?id=mlhd2021

Schmithausen, A. J., Trimborn, M., & Büscher, W. (2018). Sources of nitrous oxide and other climate relevant gases on surface area in a dairy free stall barn with solid floor and outside slurry storage. *Atmospheric Environment*, 178, 41–48.

Setoguchi, A., Oishi, K., Kimura, Y., Ogino, A., Kumagai, H., & Hirooka, H. (2022). Carbon footprint assessment of a whole dairy farming system with a biogas plant and the use of solid fraction of digestate as a recycled bedding material. *Resources, Conservation & Recycling Advances*, 15, 11.

Sommer, S.G. et al. (2000). Greenhouse gas emissions from stored livestock slurry. *Journal of Environmental Quality*, 29(3), 744–751.
https://doi.org/10.2134/jeq2000.00472425002900030009x

Živočíšna výroba, predaj výrobkov z prvovýroby a bilancia plodín 2021. (2021). ŠÚ SR.
https://slovak.statistics.sk/wps/portal/