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Assessment of microclimate and greenhouse gas emissions in dairy farms

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Abstract

This research was conducted to determine greenhouse gas (GHG) emissions and air quality parameters on dairy farm in Slovenia. A total of 48 measurements were taken, including 40 inside the barn at two different heights (1.5 m and 0.2 m) and 8 measurements outside. The study focused on the concentrations of water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ammonia (NH_3) to assess their distribution and potential environmental impact. The measured values of microclimatic parameters and gases were in accordance with the limits of optimal values, except for THI values that indicated the onset of mild heat stress. Based on the results, it was concluded that while GHG concentrations vary depending on location and measurement conditions, proper barn design and management can help maintain air quality within acceptable limits. Several factors influenced the results, including herd size, ventilation efficiency, barn management practices, and air circulation at the time of measurement. The study highlighted the importance of optimizing ventilation and manure management to reduce high gas concentrations inside dairy barns.

Key words: greenhouse gas, microclimate parameters, dairy farm

INTRODUCTION

Livestock is a major source of anthropogenic greenhouse gas (GHG) emission, and dairy farms are major contributors in this regard (Rotz, 2018). Within the farm, important emissions include enteric CH_4 from the animals (Verge et al., 2007), CH_4 and N_2O from manure in housing facilities during long-term storage and during field application, and N_2O from nitrification and denitrification processes in the soil used to produce feed crops and pasture. Dairy farming is responsible for approximately 20% of the greenhouse gas (GHG) emissions caused by all global livestock (Gerber et al., 2013). These GHG emissions exacerbate the occurrence of extreme weather events, such as severe heat and drought (IPCC et al., 2022; Donnelly et al., 2024). Dairy production contributes to GHG emissions along the chain through several processes, which include feed production, enteric fermentation, manure management, and energy use (Van Middelaar et al., 2014). Major GHGs, i.e., carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), are released during these processes, and GHG emission intensity (EI), which is defined as emissions per unit of milk produced, is usually used to express the climate impact of dairy production. The emission of carbon dioxide (CO_2) from land use depends on the demand for food grains, grazing land, and energy usage for farm operations. In addition, the decomposition of lime applied to crop and pasture land also contributes to the emission of CO_2 (Herron et al., 2022). Recently, compost-bedded pack (CBP) barn systems have received increasing attention. This system consists of an open resting area (between 20 and 30 m^2 per cow) where cows lie over their own manure, which daily composted daily “in situ” by the tillage of a rotary harrow or cultivator (Black et al., 2013). An alternative stocking rate density may require less space (minimum of 15 m^2) when feed alleys are daily scraped and the resultant slurry is removed and stored in a pile (Klaas et al., 2010). Because of the low cost and positive effects on animal welfare, health, and milk quality, this system has become an alternative to the loose-housing systems based on cubicles (Biasato et al., 2019). Nevertheless, its environmental impact on contaminant gas emissions, such as CH_4 and NH_3 is quite unknown yet, and the fact of disrupting the manure surface by tillage may support a rise in such emissions. Dairy cattle barns are generally open, and naturally ventilated and the gas emission rate is dependent on several factors, such as thermal buoyancy forces, temperature, air humidity, and air pressure on the openings of the building (Poteko et al., 2019; Leso et al., 2020). Thus, choosing the right procedure to determine gas emissions in these systems is vital to obtain reliable information. Enteric emissions are normally the largest source of GHG on a dairy farm. On well-managed confinement farms, they contribute about 45% of the total GHG emission of the full farm system, and on more-extensive grazing farms the proportion may be a little greater (Rotz & Thoma, 2017). Models using each level of detail have been used to represent enteric GHG production, which is primarily CH_4 but may include minor amounts of N_2O (Hamilton et al., 2009).

Carbon Dioxide (CO_2) is the most prevalent GHG, primarily released from the burning of fossil fuels and land-use changes. Approximately 75% of global CO_2 emissions come from industrial activities and transportation. CO_2 is also produced as a by-product of the cow's breathing process. Reducing CO_2 emissions requires a transition to renewable energy sources, improving energy efficiency, and adopting low-carbon technologies (IPCC, 2014).

Methane (CH_4) is the second most significant GHG, with emissions stemming from agriculture, particularly livestock production, as well as landfills and natural gas. Methane is most often produced during digestion in cows, especially through enteric fermentation. This gas has the potential to contribute to global warming much more than carbon dioxide on an annual basis (Gerber et al., 2013). Strategies to reduce methane emissions include optimizing livestock diets, using additives that decrease methane production during digestion, and improving manure management. The use of anaerobic digesters can also significantly reduce methane emissions from manure (Hristov et. al., 2022)

Nitrous Oxide (N_2O) is primarily released from agricultural activities, especially through the use of synthetic fertilizers. N_2O has the potential to be 298 times stronger than CO_2 in terms of heat retention (Smith et al., 2008). Reducing N_2O emissions can be achieved through precise fertilizer application, the use of cover crops, and the implementation of sustainable practices in agriculture, such as crop rotation and agroecological methods.

The aim of this research was to determine the microclimate parameters and emission of greenhouse gases on dairy cows.

MATERIAL AND METHODS

Measurements were conducted August 2024 on dairy farm Černivec in Srednje Jarše Slovenia. The farm owns 195 dairy cows, which are free-range. At least 24 measurements inside the barn, 50% at a height of 1.5 m and 50% at a height of 0.2 m and 8 measurements outside the barn at a height of 1.5 m. Each measurement took 5 minutes on the same spot. The 40 measurements were taken inside the farm in different locations, milking parlor, feeding area, maternity ward, hospital, rest area, as well as 8 measurements outside the farm. Gas concentrations were measured using a GT 5000 Terra – Splashproof multigas FTIR analyser and Multifunctional TESTO 435 for micro-climate parameters (temperature, humidity).

We measured: H_2O, CO_2, NH_3, CH_4, N_2O, Temperature (°C), Humidity (%), Air flow rate (m/s). The daily temperature humidity index values (THI) were calculated using the equation by Kibler (1964):

$$THI = 1.8\ Ta-(1-RH)\ (Ta-14.3)+32$$

where: THI – temperature humidity index, Ta – Temperature detected in stable, RH – relative humidity.

General variability of observed parameters was calculated using the descriptive statistical methods within the Statistica software package version 14.0 (TIBCO Software Inc., Palo Alto, USA).

RESULTS AND DISCUSSION

Table 1 shows results of statistical processing of the average measurement values taken from a height of 1.5 m and a height of 0.2 m, as well as total average values of both heights. Gas with the highest measured coefficient of variation (CV) both inside and outside is ammonia (NH3). Gas measurement results are expressed in the ppm unit. The average values of the outside measurement results are 2.25 (H_2O), 438.55 (CO_2), 4.13 (CH_4), 0.17 (N_2O), 0.58 (NH_3), while the average values of the inside measurement results are 2.18 (H_2O), 630.69 (CO_2), 19.70 (CH_4), 0.17 (N_2O), 2.38 (NH_3). These results are consistent with Ngwabie et al., (2009) who used a similar method of measuring greenhouse gases in dairy farms using a photoacoustic multi-gas analyzer 1412 and a multiplexer 1309. In their study, gas concentrations measured were as follows: 0.16 to 0.75 ppm N_2O, 1.70 to 17.93 ppm NH_3, 9 to 283 ppm CH_4, and 644 to 3530 ppm CO_2. EFSA (2009) concluded that cows are negatively affected by the concentration of gases in barns if it is over 3000 ppm carbon dioxide, 10 ppm ammonia and 0.5 ppm hydrogen sulphide.

Table 1. Results of gases emissions measured inside (at different heights) and outside

Different heights, (m)	Gases	N	Mean	SD	Minimum	Maximum	Range	CV%
1.5	H_2O	20	2.18	0.22	1.69	2.44	0.75	9.97
	CO_2	20	638.44	78.88	499.72	794.6	294.88	12.35
	CH_4	20	19.56	5.81	8.16	29.18	21.02	29.70
	N_2O	20	0.17	0.02	0.13	0.22	0.09	13.40
	NH_3	20	2.39	0.99	0.65	3.77	3.12	41.50
0.2	H_2O	20	2.18	0.19	1.75	2.46	0.71	8.71
	CO_2	20	622.94	87.68	474.68	771.82	297.14	14.07
	CH_4	20	19.84	7.87	7.47	35.1	27.63	39.67
	N_2O	20	0.17	0.02	0.13	0.21	0.08	11.11
	NH_3	20	2.37	0.98	1.07	4.11	3.04	41.49
Total inside	H_2O	40	2.18	0.20	1.69	2.46	0.77	9.24
	CO_2	40	630.69	82.69	474.68	794.6	319.92	13.11
	CH_4	40	19.70	6.83	7.47	35.1	27.63	34.67
	N_2O	40	0.17	0.02	0.13	0.22	0.09	12.15
	NH_3	40	2.38	0.97	0.65	4.11	3.46	40.96
Total outside	H_2O	8	2.25	0.07	2.17	2.35	0.18	3.01
	CO_2	8	438.55	30.07	418.92	509.95	91.03	6.86
	CH_4	8	4.13	2.80	2.31	10.79	8.48	67.69
	N_2O	8	0.17	0.00	0.17	0.17	0.00	0.00
	NH_3	8	0.58	0.46	0.31	1.67	1.36	79.70

SD - Standard deviation; CV% - Coefficient of variation

Table 2 displays the results obtained from a height of 1.5 m and a height of 0.2 m, as well as the total average values of both heights, microclimate parameter with the highest measured coefficient of variation (CV) both inside and outside is air flow (AIR). The microclimatic parameters processed include: Air (m/s), RH (%), T (°C), THI (%). The average values of the outside measurement results are 1.10 (AIR), 34.93 (RH), 35.81 (Tc), while the average values of the inside measurement results are 0.49 (AIR), 62.86 (RH), 26.17 (Tc), 74.63 (THI). The accuracy of the measurements was influenced by numerous factors, because the barn, in addition to artificial ventilation, also has natural ventilation in the form of large openings on the side walls. Many authors have defined optimal temperature values in facilities for dairy cows. So, for example, according to Hristov (2002) and Ensminger (1977), the optimal temperature values in facilities for dairy cows are 10-15°C. According to Hristov (2002) and Ensminger (1977) the comfort zone is 5-21°C, according to Sambraus (1997) 0-20°C. Acceptable relative air humidity in dairy barns is 50-75%, according to Čobić and Antov (1996) and Hristov (2002), while Sambraus et al. (2002) believe that in the biozone of dairy cows, it is necessary to ensure a relative humidity of 60-80%.

Table 2. Results of microclimate parameters and THI values measured inside (at different heights) and outside

Different heights, (m)	Microclimate parameters	N	Mean	SD	Minimum	Maximum	Range	CV%
1.5	AIR	20	0.39	0.20	0.15	0.84	0.69	49.96
	RH	20	63.09	5.12	53.8	69.1	15.3	8.11
	Tc	20	26.05	1.57	23.7	28.5	4.8	6.01
	THI	20	74.49	1.81	71.68	77.18	5.5	2.44
0.2	AIR	20	0.60	0.50	0.13	1.93	1.80	83.52
	RH	20	62.63	5.30	50.80	68.20	17.40	8.46
	Tc	20	26.30	1.66	23.90	28.60	4.70	6.32
	THI	20	74.77	1.82	71.86	77.30	5.44	2.43
Total inside	AIR	40	0.49	0.39	0.13	1.93	1.80	78.38
	RH	40	62.86	5.15	50.80	69.10	18.30	8.19
	Tc	40	26.17	1.60	23.70	28.60	4.90	6.11
	THI	40	74.63	1.80	71.68	77.30	5.62	2.41
Total outside	AIR	8	1.10	0.90	0.09	2.36	2.27	81.64
	RH	8	34.93	2.56	30.90	38.40	7.50	7.32
	Tc	8	35.81	0.91	34.20	36.90	2.70	2.53

SD - Standard deviation; CV% - Coefficient of variation

In Figure 1, the first column represents the air temperature in the barn, the first row shows the percentage of air humidity, the values within the table itself represent the calculated value of THI, which is obtained by a specific equation. The colors in the table indicate different levels of stress sensitivity. THI values (74.63) show that conditions for mild heat stress were occurring in the barn during the measurement period. Identifying critical THI thresholds can help farm staff or inside controllers to initiate cooling systems in a timely fashion to maintain cows' productivity and ensure animal welfare (Geqi Yan et al., 2021). Zimbelman et al. evaluated the impact of THI on changes in the milk production of cows in the southern US and declared the critical threshold as 68 THI. When the ambient temperature exceeds the upper limit of a certain temperature range, heat stress is triggered and then negatively affects the production, reproduction, health, and welfare of livestock animals (Geqi Yan et al., 2021). The effects of the THI, age at calving, stage of lactation, parity and calving season were very highly significant ($p<0.001$) for daily milk yield (Kučević et al., 2013). In addition, they found that for each THI unit increase, milk yield decreases. Appropriate ventilation is an essential requirement to ensure animal welfare and efficient and sustainable production since a proper ventilation is the most efficient way to remove undesirable air pollutants and to obtain a comfortable microclimate for the welfare of the animals (Santolini et. al., 2024). In the calculation of the THI value the air temperature is the most influential feature. THI values will be considered as an indicator for the effects of heat stress. For example, following the values reported in (National Research Council, 1971) for dairy cows, THI values > 72 indicate slight stress level, THI > 78 indicates a moderate stress level, THI > 88 indicates conditions of serious stress and for value of THI > 98 dangerous level with high risk of death for animals. For THI

≤ 72 the climate conditions do not induce heat stress on the cows (Bernabucci et al., 2014; Berman et al., 2016; Carabano et al., 2016; Moretti et al., 2017; Ji et al., 2020; Muschner-Siemens et al., 2020). Furthermore, the THI value is used for the assessment of the possible drop in the production associated to heat stress conditions (Bovo et al., 2021).

Temperatura		vlažnost vazduha [%]																		
°F	°C	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
72	22,0	64	65	65	65	66	66	67	67	67	67	68	68	69	70	70	70	70	71	71
73	23,0	65	65	66	66	66	67	67	68	68	68	69	69	70	70	71	71	71	72	72
74	23,5	65	66	66	66	67	67	68	68	69	69	70	70	70	71	71	72	72	73	73
75	24,0	66	66	67	67	68	68	68	69	69	70	70	71	71	72	72	73	73	74	74
76	24,5	66	67	67	67	68	69	69	70	70	71	71	72	72	73	73	74	74	75	75
77	25,0	67	67	68	68	69	69	70	70	71	71	72	72	73	73	74	74	75	75	76
78	25,5	67	68	68	68	69	70	70	71	71	72	73	73	74	74	75	75	76	76	77
79	26,0	67	68	69	69	70	70	71	71	72	73	73	74	74	75	76	76	77	77	78
80	26,5	68	69	69	69	70	71	72	72	73	74	74	75	75	76	76	77	78	78	79
81	27,0	68	69	70	70	71	72	72	73	73	75	75	75	76	77	77	78	78	79	80
82	28,0	69	69	70	70	71	72	73	73	74	75	75	76	77	77	78	79	79	80	81
83	28,5	69	70	71	71	72	73	73	74	75	76	76	77	78	78	79	80	80	81	82
84	29,0	70	70	71	72	73	73	74	75	75	77	77	78	78	79	80	80	81	82	83
85	29,5	70	71	72	72	73	74	75	75	76	78	78	78	79	80	81	81	82	83	84
86	30,0	71	71	72	73	74	74	75	76	77	78	78	79	80	81	81	82	83	84	84
87	30,5	71	72	73	73	74	75	76	77	77	79	79	80	81	81	82	83	84	85	85
88	31,0	72	72	73	74	75	76	76	77	78	80	80	81	81	82	83	84	85	86	86
89	31,5	72	73	74	75	75	76	77	78	79	80	80	81	82	83	84	85	86	86	87
90	32,0	72	73	74	75	76	77	78	79	79	81	81	82	83	84	85	86	86	87	88
91	33,0	73	74	75	76	76	77	78	79	80	82	82	83	84	85	86	86	87	88	89
92	33,5	73	74	75	76	77	78	79	80	81	82	83	84	85	85	86	87	88	89	90
93	34,0	74	75	76	77	78	79	80	80	81	83	83	85	85	86	87	88	89	90	91
94	34,5	74	75	76	77	78	79	80	81	82	84	84	86	86	87	88	89	90	91	92
95	35,0	75	76	77	78	79	80	81	82	83	85	85	86	87	88	89	90	91	92	93
96	35,5	75	76	77	78	79	80	81	82	83	85	86	87	88	89	90	91	92	93	94
97	36,0	76	77	78	79	80	81	82	83	84	86	86	87	88	89	91	92	93	94	95
98	36,5	76	77	78	80	80	82	83	83	85	87	87	88	89	90	91	92	93	94	95
99	37,0	76	78	79	80	81	82	83	84	85	87	88	89	90	91	92	93	94	95	96
100	38,0	77	78	79	81	82	83	84	85	86	88	88	90	91	92	93	94	95	96	98
101	38,5	77	79	80	81	82	83	84	86	87	89	89	90	92	93	94	95	96	98	99
102	39,0	78	79	80	82	83	84	85	86	87	89	90	91	92	94	95	96	97	98	100
103	39,5	78	79	81	82	83	84	86	87	88	90	91	92	93	94	96	97	98	99	101
104	40,0	79	80	81	83	84	85	86	88	89	91	91	92	94	95	96	98	99	100	101
105	40,5	79	80	82	83	84	86	87	88	89	91	92	93	95	96	97	99	100	101	102
106	41,0	80	81	82	84	85	87	88	89	90	91	93	94	95	97	98	99	101	102	103
107	41,5	80	81	83	84	85	87	88	89	91	92	94	95	96	98	99	100	102	103	104

Figure 1. Temperature range according to temperature-humidity index (THI)
[mod. according to Lallemand Animal Nutrition, 2015]

Interpretation of THI values:

- ❖ Optimal, without heat stress.
- ❖ Warning; possible slight increase in stress.
- ❖ Moderate stress; intervention is required.
- ❖ Heavy stress; livestock health may be at risk.
- ❖ Extreme stress; serious consequences for health and productivity.

CONCLUSION

Higher values were determined at a height of 0.2 m, while lower values were determined at a height of 1.5 m. Based on the results of greenhouse gas measurements and the obtained values, it can be concluded that the different height in the barn affects the measurement results. The measured values of microclimatic parameters and gases were in accordance with the values of optimal limits. THI values showed that conditions for mild heat stress were occurring in the barn during the measurement period. Also, a farm that was built in compliance with all measures and regulations, has good ventilation and enough space for the cow, does not emit enormous amounts of gases that can have a harmful effect on the environment. Implementing effective mitigation strategies is essential for reducing the environmental impact of the industry while maintaining productivity and animal welfare. Sustainable housing systems, such as compost-bedded pack barns, offer improvements in manure management, cow comfort, and air quality, leading to lower emissions and enhanced overall farm efficiency.

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