Influence of housing system and season on methane and carbon dioxide concentrations in a dairy cattle barn

M. Bric, M. Podgornik Milosavljević, T. Perčič, S. Rogina and M. Klopčič

University of Ljubljana, Biotechnical faculty, Department of Animal Science, Groblje 3, 1230 Domžale, Slovenia
Corresponding author: marija.klopcic@bf.uni-lj.si

Abstract

Cattle barns are an important source of greenhouse gasses (GHG). In buildings for dairy cattle, the interaction of weather conditions and microclimatic parameters have an influence on the emission of GHG. The aim of the study was to determine the effects of the housing system and the seasons on the concentration of methane and carbon dioxide in dairy cattle barns. As part of the EIP-AGRI project "Innovative environmental and climate-based management systems of cattle farms to ensure feed production and optimal conditions for rearing cattle", we carried out monthly CH_4 and CO_2 concentration measurements at different points in the dairy cattle barn of ten farms with different housing systems (tied-in housing system, loose housing with cubicles and slatted floor or with concrete floor, compost bedded pack barn, deep straw housing and innovative housing system with permeable floor). The measurements were carried out from July 2022 to October 2023 at a height of 1.5 m. Each measurement lasted 5 minutes. For the measurements we used the portable gas analyser GASMET GT5000 Terra. In addition to greenhouse gas concentrations, microclimate parameters (temperature, relative humidity and air flow) were also measured using a TESTO 435 multimeter. Based on the 4,633 measurements, we find that there are differences in the measured CH_4 and CO_2 concentrations between farms with different housing systems, different methods of removal and storage animal secretions and in terms of measurement time. We find that, on average, the lowest CH_4 concentrations (11.46 ± 8.83 ppm) were measured in compost bedded pack barns and the lowest CO_2 concentrations (517.67 ± 85.13 ppm) in deep straw barn. The highest concentration of CH_4 (33.24 ± 23.40 ppm) and CO_2 (787.49 ± 254.12 ppm) was measured in barns with tied-in housing. The lowest concentration of CH_4 (17.70 ± 11.21 ppm) was measured in June 2023 and of CO_2 (558.04 ± 126.55 ppm) in August 2022. The concentrations of CH_4 and CO_2 measured in the winter months were on average higher than the concentrations measured in the summer months. Higher CH_4 and CO_2 concentrations were found in closed barns where air flow was poorer. The differences between the CH_4 and CO_2 concentrations measured in the summer and winter months were smaller in more open barns. A correlation coefficient of 0.755 indicates a relatively strong linear relationship between CH_4 and CO_2 concentrations. This means that changes in CH_4 concentrations are closely associated with corresponding changes in CO_2 concentrations across the measured data points and vice versa.

Keywords: cattle, dairy cows, housing system, methane, carbon dioxide, season, Slovenia.
Presented at the ICAR Anual Conference 2024 in Bled at the Session 11: Methane Emission-Free Communications: Genetics, Environmental, and Life Cycle Assessment Studies

Introduction

Methane (CH_4) is a greenhouse gas (GHG) whose global warming potential is 23 times higher than that of carbon dioxide (CO_2) (IPCC, 2001). Enteric fermentation and manure management account for 35 to 40 % of total anthropogenic CH_4 emissions and 80 % of CH_4 released from agriculture (FAO, 2006). With the intensification of milk production, dairy cattle barns have been identified as an important source of GHG emissions (Qu *et al.,* 2021). Quantifying GHG emission rates in dairy cattle barns with natural ventilation is a challenging task, as many different factors influence the release of these emissions (Samer *et al.,* 2011), but if done properly, it could contribute to the development of accurate emission inventories and effective mitigation strategies (Qu *et al.,* 2021). Therefore, it is necessary to carry out this type of research on farms under realistic conditions if we want to obtain representative and reliable measurement results. Conducting the trial on several farms at the same time (multi-farm trial) contributes to more reliable results. In addition, attention must be paid to representative sampling, which requires an appropriate spatial distribution of the measurement locations within the barns. In order to take into account, the influence of climatic factors, measurements must be carried out throughout the year (Schrade *et al.,* 2012). Indeed, the climatic conditions surrounding livestock buildings are considered to be an extremely important factor for GHG emissions, as these conditions are likely to be essential for naturally ventilated buildings, as they have a direct influence on the ventilation rate and most likely also on the emission rate (Ngwabie *et al.,* 2009). Numerous studies have shown that heat stress, which is a function of relative humidity and air temperature, affects both the behaviour and performance of dairy cows (Joo *et al.,* 2015; West, 2003). Therefore, further research into the effects of environmental factors on GHG emissions from dairy cattle barns is important (Joo *et al.,* 2015).

The aim of the study was to determine the influence of the housing system and the season on the CH_4 and CO_2 concentrations in ten different dairy cattle barns with different housing systems.

Material and methods

As part of the EIP - AGRI project "Innovative environmental and climate-based management systems of cattle farms to ensure feed production and optimal conditions for rearing cattle", we carried out monthly measurements of CH_4 and CO_2 concentrations on ten milk production-oriented farms with different housing systems. The study therefore included three dairy cattle barns with cubicles and slatted floors (farm 2, farm 3 and farm 6), one dairy cattle barn with cubicles and concrete floor (farm 7), two compost bedded pack barns (farm 8 and farm 9), two barns with tied-in housing system (farm 4 and farm 10), one barn with deep straw housing (farm 5) and one farm with an innovative housing system with a permeable floor (farm 1). The measurements were carried out from July 2022 to October 2023 at a height of 1.5 m above the floor at various locations within the barns: in the feeding alley, on the cow traffic routes, in the lying alley and in the young stock housing area (Figure 1). Each measurement at each selected location inside and outside the barn lasted 5 minutes. The GHG concentrations were measured with a portable gas analyser Gasmet GT5000 Terra. It works on the principle of FTIR technology (Fourier transform infrared spectroscopy), which enables fast, accurate and reliable measurements of up to 300 different gas components simultaneously based on the absorption of IR light (Gasmet, 2022). In addition to the GHG concentrations, microclimate parameters (temperature, relative humidity and air flow) were also measured at the same locations as the GHG measurements. These measurements were carried out using a Testo 435 Multi-Metre.

The data analysis of the measurements of greenhouse gas concentrations and microclimate parameters was carried out using the SAS Stat statistical package. We were interested in the effects of different housing systems and the influence of season on the concentrations of CH_4 and CO_2 in different housing systems for dairy cows. For the statistical analysis we used two different statistical models. The systematic part of both models was developed using the least square means method with the GLM procedure in the SAS statistical package, and the differences within each influence were tested using analysis of variance (ANOVA) (F-test).

In the first model, CO_2 was used as a variable, and in the systematic part of the model, M was used as the month, F as the farm where we took the measurements, and T(M) as the housing system nested within the month. The influence of CH_4 concentrations was included in the model in the form of a linear regression (see equation 1). The systematic influence of the month of measurement had a statistically significant influence on CO_2 concentrations (p<0.0001), as did the systematic influence of the farm (*P* <0.0001) and the influence of the housing system within the month (*P* <0.0001). In addition to the systematic influences on the CO_2 concentrations, the CH_4 concentrations in the barn also had a statistically significant influence (p<0.0001). With this model, we were able to explain 78.99 % of the variance (R^2 = 78.99 %).

$$y_{ijkl} = \mu + M_i + F_j + T_{ki} + b_1 (x_{ijk} - \bar{x}) + e_{ijkl} \qquad (1)$$

In the second model, we used CH_4 concentration as a variable, and in the systematic part of the model, we used M as the month, F as the farm where the measurements were taken, and T(M) as the housing system nested within the month of the measurements. A linear regression coefficient was used for the influence of CO_2 concentration (see equation 2). The influence of the month and the influence of the farm had a statistically significant influence on the measured CH_4 concentrations in the barn (*P*<0.0001), the same applies to the influence of the housing system, which was nested within the month and the influence of the linear regression (*P* <0.0001). With the second model, we were able to explain 72.29 % of the variance (R^2 = 72.29 %).

$$y_{ijkl} = \mu + M_i + F_j + T_{ki} + b_2 (x_{ijk} - \bar{x}) + e_{ijkl} \qquad (2)$$

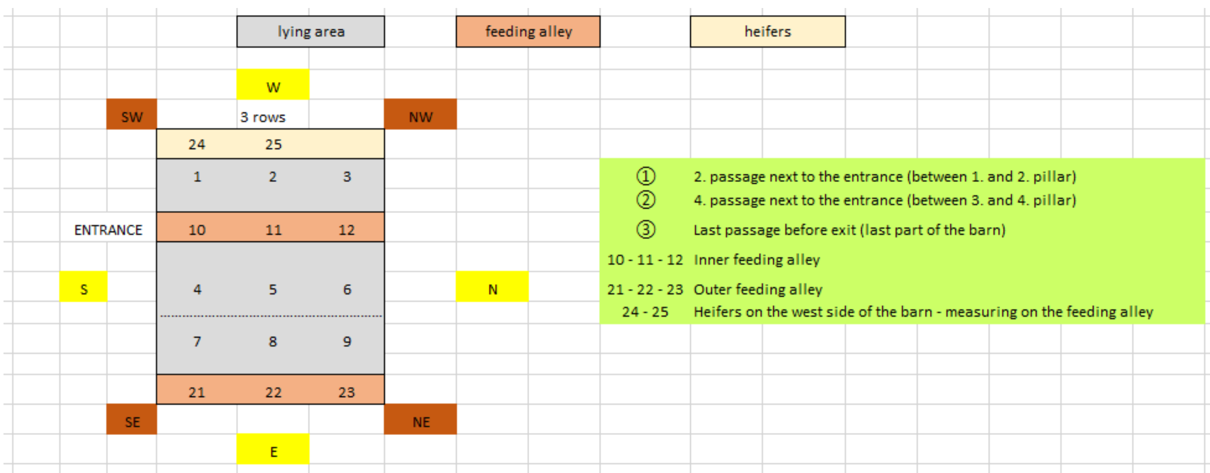

Figure 1. Schematic representation of the measuring points in the barn.

Results and discussion

Based on the 4,633 measurement results, we find that there are differences in the measured CH_4 and CO_2 concentrations between the individual farms with different housing systems, different methods of removal and storage of animal secretions and with regard to the measurement time. On average, the lowest CO_2 concentrations (529.09 ± 51.71 ppm) were measured in deep straw barn and the highest (833.54 ± 204.90 ppm) in barns with tied-in housing system. In August 2022, when the average air temperature was 23.64°C ± 3.05°C and the average relative humidity was 63.98 % ± 9.05 %, CO_2 concentrations (558.04 ± 126.55 ppm) were the lowest on average, and in March 2023, when the average air temperature was 11.26°C ± 4.14°C and the relative humidity was 57.86 % ± 13.77 %, the measured CO_2 concentrations were the highest on average (789.77 ± 240.88) (Figure 2, Table 1).

On average, the lowest CH_4 concentrations (10.23 ± 3.00 ppm) were recorded in compost bedded pack barns and the highest similar to the CO_2 concentrations, in barns with tied-in housing (36.38 ± 14.54 ppm) (Figure 3). The CH_4 concentrations measured in the winter months were on average higher than the concentrations measured in the summer months. The lowest CH_4 concentrations (17.69 ± 11.21 ppm) were measured in June 2023, when the average air temperature was 21.15°C ± 2.59°C, and the average relative humidity was 63.28 % ± 10.86 %. The highest average CH_4 concentrations (28.51 ± 21.32 ppm) were measured in January 2023, when the average air temperature was 5.74°C ± 3.82°C, and the average relative humidity was 72.92 % ± 6.16 % (Table 1).

The concentrations of the two gases investigated, CH_4 and CO_2, were on average higher in the winter months than the concentrations measured in the summer months. The

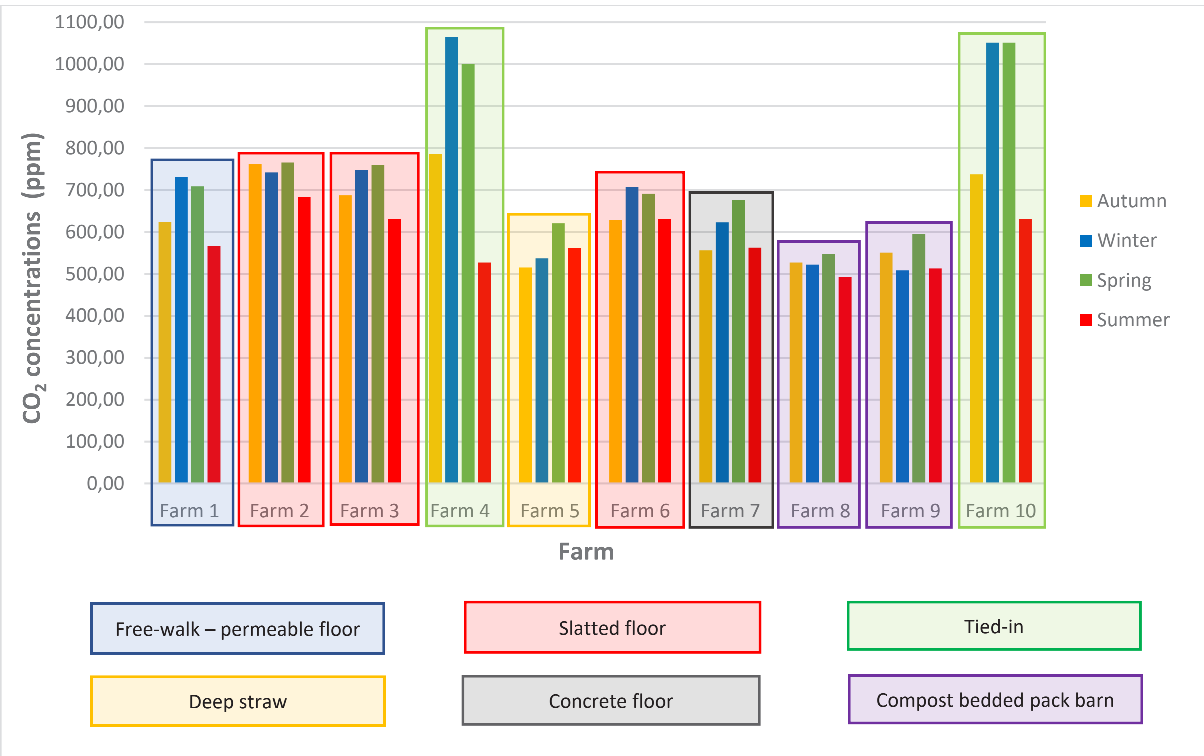

Figure 2. Differences in average CO2 concentrations between farms and seasons.

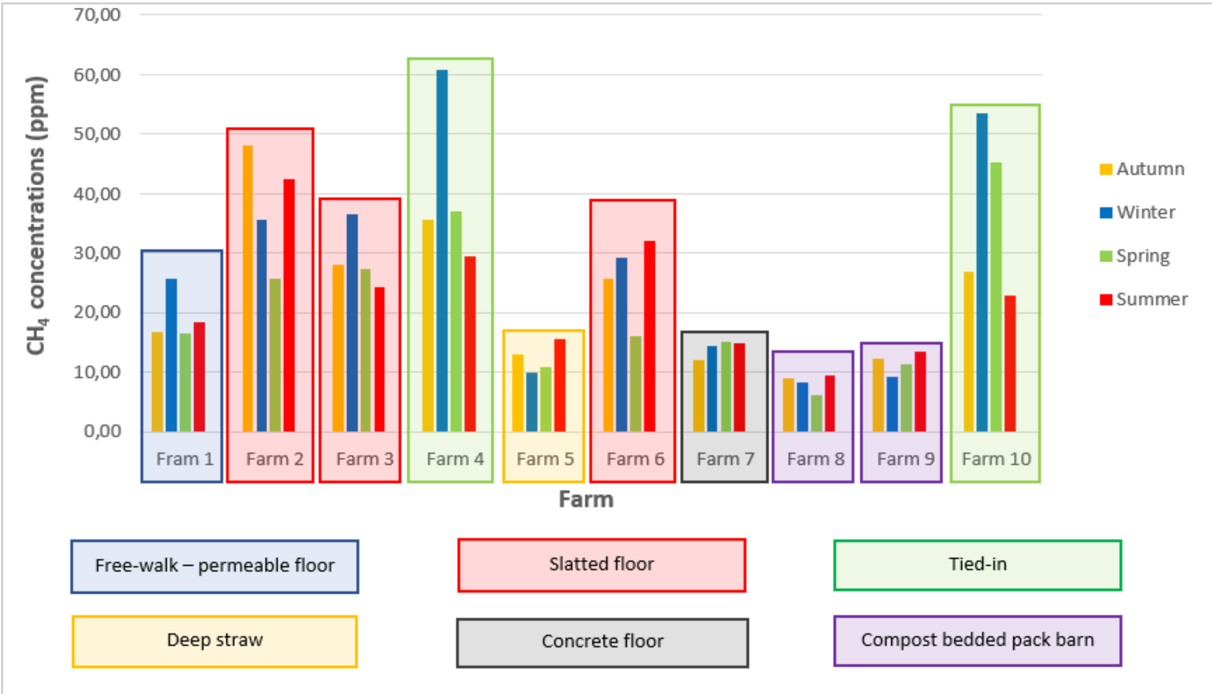

Figure 3. Differences in average CH4 concentrations between farms and seasons.

Table 1. Descriptive statistics (mean and STD) for CO2 and CH4 concentrations in the different measurement months.

Month	N	CO_2 (ppm)	CH_4 (ppm)	Temperature (°C)	Humidity (%)
July 2022	294	594.53 ± 136.93	21.92 ± 25.40	25.59 ± 2.72	54.63 ± 11.82
August 2022	277	558.04 ± 126.55	25.11 ± 27.32	23.64 ± 3.05	63.98 ± 9.05
September 2022	329	582.01 ± 121.13	21.83 ± 17.25	16.33 ± 2.65	71.66 ± 8.71
October 2022	311	631.67 ± 142.09	21.53 ± 15.54	15.78 ± 2.02	71.64 ± 8.71
November 2022	311	673.82 ± 192.92	20.45 ± 18.00	7.87 ± 3.46	75.17 ± 5.52
December 2022	277	662.97 ± 179.67	21.72 ± 16.08	4.64 ± 3.04	73.83 ± 5.49
January 2023	295	726.58 ± 237.17	28.51 ± 21.32	5.74 ± 3.82	72.92 ± 6.16
February 2023	277	695.35 ± 255.34	26.55 ± 24.43	5.35 ± 3.74	62.05 ± 8.38
March 2023	311	789.77 ± 240.88	24.17 ± 21.52	11.26 ± 4.14	57.86 ± 13.77
April 2023	277	752.00 ± 209.69	19.47 ± 16.81	12.60 ± 2.86	51.21 ± 13.27
May 2023	311	596.52 ± 144.07	17.76 ± 11.55	16.47 ± 2.27	64.83 ± 9.29
June 2023	277	570.12 ± 131.80	17.69 ± 11.21	21.15 ± 2.59	63.28 ± 10.86
July 2023	275	609.24 ± 152.27	23.64 ± 20.05	23.38 ± 3.05	70.16 ± 9.07
August 2023	277	570.96 ± 112.32	21.07 ± 20.36	20.82 ± 2.88	68.73 ± 9.08
September 2023	259	614.34 ±143.10	26.05 ± 25.28	20.91 ± 3.11	65.77 ± 17.35
October 2023	277	575.33 ± 133.58	24.37 ± 26.06	14.73 ± 3.49	72.70 ± 8.03

differences between the CH_4 and CO_2 concentrations measured in the summer and winter months were smaller in more open barns. We also found that higher CH_4 and CO_2 concentrations were detected in more closed barns where airflow was poorer. Qu *et al.* (2021) indicate that CH_4 emission rates tend to increase with increasing temperature. Poteko *et al.* (2019) also find similar findings. In their report, Joo *et al.* (2015) investigated the influence of environmental factors on various GHG concentrations. They found that air temperature had the greatest influence on the increased CO_2 concentrations in the dairy cattle barn, while the contribution of relative humidity had the least influence. Similar to CO_2 concentrations, elevated CH_4 concentrations in the barn were significantly influenced by air temperature and air velocity, while the contribution of by relative air humidity was the smallest (Joo *et al.,* 2015). The air temperature between 5°C and 25°C is referred to as the thermoneutral range for lactating dairy cows. Outside this comfort zone, animal activity can be negatively affected, resulting in low metabolism, reduced appetite, low CO_2 levels in the bloodstream and lower respiration, which in turn leads to lower CO_2 emissions (West, 2003). High temperatures, which reduce the time cows devote to eating and rumination, also lead to a reduction in the amount of CH_4 produced (Ngwabie *et al.,* 2011). However, Qu *et al.* (2021) note that data synthesis shows large differences between CH_4 emission rates in dairy cow barns in different publications.

A correlation coefficient of 0.755 indicates a relatively strong linear relationship between CH_4 and CO_2 concentrations, which is in line with the results of Joo *et al.* (2015) (R^2 = 0.67 – 0.74). This implies that changes in CH_4 concentrations are closely associated with corresponding changes in CO_2 concentrations and vice versa, across the measured data points, due to the common origin (enteric fermentation and respiration) in ruminants (Joo *et al.,* 2015).

Conclusions

In the future, it is expected that major changes will be required from agriculture in terms of reducing greenhouse gas emissions (Pathak *et al.,* 2013). Quantifying gas emission rates in dairy cow barns could help to develop accurate emission inventories and effective mitigation strategies (Qu *et al.,* 2021). Estimates of gas emissions in dairy barns are highly dependent on the measurement of ventilation rates and gas concentration (Qu *et al.,* 2021). Changes in some husbandry practices with the aim of reducing GHG emissions, such as feed production strategies and feeding practices, animal housing facilities, animal excreta handling practices, etc., will be a major challenge for agriculture in the future (Pathak *et al.,* 2013), but at the same time could help to tackle climate change and improve air quality on a large scale (Hassouna *et al.,* 2016).

List of references

FAO, 2006. Livestocks long Shadow. https://www.fao.org/4/a0701e.pdf

Gasmet, 2022. GT5000 Terra – Splashproof multigas FTIR analyzer. https://www.gasmet.com/products/category/portable-gas-analyzers/gt5000-terra/

Hassouna, M., T. Eglin, P. Cellier, V. Colomb, J. P. Cohan, C. Decuq, M. Delabuis, N. Edouard, S. Espagnol and M. Eugene, 2016. Measuring Emissions from Livestock Farming: Greenhouse gases, Ammonia and Nitrogen oxides. Ademe – INRA, 314pp.

IPCC, 2001. Third assessment report climate change. The scientific basis.

Joo H. S., P. M. Ndegawa, A. J. Heber, J.-Q. Ni, B. W. Bogan, J. C. Ramirez-Dorronsoro and E. Cortus, 2015. Greenhouse gas emissions from naturally ventilated freestall dairy barns. Atmospheric Environment, 102: 384-392.

Ngwabie N. M., K. H. Jeppsson, S. Nimmermark, C. Swensson and G. Gustafsson, 2009. Multi-location measurements of greenhouse gases and emission rates of methane and ammonia from a naturally-ventilated barn for dairy cows. Biosystems Engineering, 103: 68-77.

Ngwabie N. M., K. H. Jeppsson, G. Gustafsson and S. Nimmermark, 2011. Effects of animal activity and air temperature on methane and ammonia emissions from a naturally ventilated building for dairy cows. Atmospheric Environment, 45, 37: 6760-6768.

Pathak H., R. C. Upadhyay, M. Muralidhar, P. Bhattacharyya and B. Venkateswarlu, 2013. Measurement of Greenhouse Gas Emission from Crop, Livestock and Aquaculture. Indian Agricultural Research Institute, New Delhi, 101pp.

Poteko J., M. Zähner and S. Schrade, 2019. Effects of housing system, floor type and temperature on ammonia and methane emissions from dairy farming: A meta-analysis. Biosystems Engineering, 182: 16-28.

Qu Q., J. C. J. Groot, K. Zhang and R. P. O. Schulte, 2021. Effects of housing system, measurement methods and environmental factors on estimating ammonia and methane emission rates in dairy barns: A meta-analysis. Biosystems Engineering, 205: 64-75.

Samer M., C. Loebsin, M. Fiedler, C. Ammon, W. Berg, P. Sanftleben and R. Brunsch, 2011. Heat balance and tracer gas technique for airflow rates measurement and gaseous emissions quantification in naturally ventilated livestock buildings. Energy and Buildings, 43: 3718-3728.

Schrade S., K. Zeyer, L. Gygax, L. Emmenegger, E. Hartung and M. Keck, 2012. Ammonia emissions and emission factors of naturally ventilated dairy housing with solid floors and an outdoor exercise area in Switzerland. Atmospheric Environment, 47: 183-194.

West J. W., 2003. Effects of Heat-Stress on Production in Dairy Cattle. Journal of Dairy Science, 86 (6): 2131-2144.