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Research Paper

Providing indoor and outdoor exercise to dairy cows: Assessment of effluent properties and gas emissions

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ABSTRACT

Enhancing movement options for confined dairy cows, like in tie-stall housing, may boost natural behaviour and welfare. Yet, limited data exists on the environmental impact of both indoor and outdoor exercise areas. This study investigates the impact of exercise pen type on effluent properties and gas emissions during winter and/or summer conditions in a northern country such as Canada. Forty-five Holstein dairy cows were randomly assigned to three treatments: (1) no exercise [cows kept indoors with tie-stalls (TSs)]; (2) indoor exercise [access to a 28 m^2 cow^{-1} indoor pen (IP) for 1.5 h d^{-1}] and (3) outdoor exercise [access to a 28 m^2 cow^{-1} outside nonaerated (OnAP) or aerated stand-off pad (OAP) for 1.5 h d^{-1}]. The effluent composition of OnAP and OAP varied notably between seasons. In winter, OAP leachates showed higher biological oxygen demand (+89 %), pH (+1.2 units), ammonium (+96 %) and total solids (+50 %), lower faecal but higher total coliforms (−120 % and +20 %, respectively) than OnAP during summer. In addition, OAP presented higher biological and chemical oxygen demand (+80 %) than OnAP in both seasons. Both OAP and OnAP showed higher carbon dioxide emissions (+150 %) and lower methane emissions during summer (−200 %) than IP and TS. Nitrous oxide emissions were higher for OnAP (+600 %) than in OAP, IP and TS, with no changes in ammonia emissions across treatments. Outdoor exercise for dairy cows using a filtering pen didn't meet environmental limits for removing leached contaminants. Exercise pens raised carbon dioxide and nitrous oxide emissions but decreased methane emissions.

1. Introduction

Tie-stall (TS) housing is a common practice for raising dairy cows in Eastern Canada (89 %; MAPAQ, 2018). This indoor confinement system allows dairy producers to provide high-yielding cows with a nutritionally balanced diet that meets all their needs. Nevertheless, TS housing raises many issues from an animal welfare perspective (Schuppli et al., 2014). Previous studies have rightly shown strong preferences for more natural environments (Boogaard et al., 2011; Krystallis et al., 2009; Vanhonacker et al., 2008) and general opposition to restriction of movement (Boogaard et al., 2011; Lassen et al., 2006; Miele et al., 2011).

TSs, due to their restrictive conditions, can lead to various health issues in animals: lameness, sole ulcers, interdigital dermatitis, dystocia and endometritis. TSs can also hinder the normal behavioural development of animals (Krohn et al., 1992; Olmos et al., 2009; Sheldon et al., 2006) and have been linked to adverse effects on the overall health and lifespan of animals (Horn et al., 2012; Oltenacu & Broom, 2010). These conditions increase the risk of involuntary culling, which has consequences for productivity. Regarding indoor tie-tall and loose housing, providing exercise areas to dairy cows contributes to the improvement of their well-being (Shepley et al., 2020), reducing lameness, recovery from hoof and leg injuries (Hernandez-Mendo et al., 2007), a decrease in udder infections such as clinical mastitis (Washburn et al., 2002) and increased motivation for locomotion exercises (Veissier et al., 2008). After a 1-year-long follow-up of outdoor access during the day (~6 h), issues such as lameness and knee injuries were reduced by 20 % and 16 % compared to dairy cows without outdoor access (Palacio et al., 2006). Nevertheless, the outdoor access might also have downsides. Baird et al. (2009) found that the claws of cows housed in pastures during the day in summer show higher damage than those kept indoors with concrete floors, although this was associated with soil conditions (the ground was often rough, and stones were visible at the surface). In addition, on

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Nomenclature table

Abbreviations	*Definition*
BOD (mg L^{-1})	Biological oxygen demand
CFU (× 100 mL^{-1})	Colony-forming unit
COD (mg L^{-1})	Chemical oxygen demand
GHG	Greenhouse gas
IP	Inside pen
NH_4–N (mg L^{-1})	Ammonium
NO_3+NO_2 (mg L^{-1})	Nitrates and nitrites
OAP	Outside aerated stand-off pad
OnAP	Outside non-aerated stand-off pad
RNC	National Research Council
SS (mg L^{-1})	Suspended solids
TS	Tie-stall

pasture, the risk of contracting white line disease might increase (Barker et al., 2009). The Canadian Code of Practice for the care and handling of dairy cattle suggests that the time spent on concrete surfaces should be reduced because it increases the risk of lameness and foot infections (National Farm Animal Care Council, 2023). Therefore, there is still a lack of knowledge about whether the exercise pen should be located outside or inside the barn. TSs are a common practice at the national level, which is approximately 73 % (Canadian Dairy Information Centre, 2023). In the province of Quebec, Canada, the dairy sector has the largest agricultural production in terms of economics (MAPAQ, 2018).

Labelle et al. (2016) proposed practical solutions for dairy farmers to provide exercise to lactating cows. This approach was estimated considering an average biological herd of 55 lactating dairy cows in Quebec conditions. Most options included building another free-stall barn with associated costs of more than $300,000 CAD. Thus, two low-cost alternatives that can be used only by a part of the herd at the same time were also described: reconfiguring a portion of the tie-stall barn in a free moving area ($5000 CAD cow^{-1}) or building an outdoor wintering site consisting of a wintering pen and a vegetative filter strip ($1000 CAD cow^{-1}). However, the latter system must respect Quebec's stringent environmental regulations (Q-2, r. 26—Règlement sur les exploitations agricoles, articles 17 and 18), stipulating that contaminated runoff water from livestock yards must not percolate into ground waters or discharge into surface waters. This is because the contaminants in leachate can be several times higher than those found in typical dairy farm effluent. Usually, leachate is rich in nitrogen, potassium and faecal microbes such as faecal coliforms (Luo et al., 2008). A working team led by the Research and Development Institute for the Agri-Environment (IRDA) concluded after 15 years of research on wintering sites for beef cattle that none of the proposed configurations is always 100 % effective in ensuring zero polluting release annually (Pelletier et al., 2016).

Consequently, a similar outdoor approach could be a stand-off pad consisting of a woodchip pad overlying an impermeable lining with drainage pipes to deliver effluent to a tank. This system is well established in Ireland, the United Kingdom and New Zealand, where it is considered an economic means of wintering dairy cows without compromising animal performance, health or welfare, treating soiled water through a woodchip matrix, which acts as a filtration and retention medium of slurry solids and captures all the remaining effluent (Basden et al., 2015; Dairy N.Z., 2017; Smith et al., 2010, pp. 1–42). Another advantage of stand-off pads is the possible reduction in gaseous emissions of ammonia (NH_3) and nitrous oxide (N_2O), since the rapid drainage of effluent from the surface would reduce the scope for rapid urea hydrolysis and subsequent nitrogen diffusion into the air. In addition, to improve the treatment of leachates and decrease the volume of water to be managed, air injection into the filtering material could be implemented.

Currently, neither the indoor dedicated exercise pen nor the outdoor stand-off pad has been evaluated under controlled conditions to assess their environmental impact. This study aims to investigate potential contamination and gas emissions when providing exercise to dairy cows from TS barns under typical Canadian conditions (i.e. a humid continental climate characterised by hot summers and cold winters and conditions considered neither arid nor semiarid). Therefore, during the winter and summer periods, (a) the quality of water flowing through nonaerated and aerated stand-off pads was examined and (b) NH_3 and greenhouse gas (GHG) emissions were measured from TSs and indoor and outdoor exercise areas.

2. Materials and methods

2.1. Experimental setup and design

The experiment was conducted at the dairy research barn of the Centre de Recherche en Sciences Animales de Deschambault (CRSAD, Deschambault, QC, Canada) during two 9-week periods in 2020: from 27 January to 21 March (winter conditions) and from 29 June to 28 August (summer conditions). A total of 45 Holstein multiparous lactating dairy cows [27 cows in winter (9 groups of 3 cows) and 18 in summer (6 groups of 3 cows)] were randomly selected. The cows were housed in TSs, and they did not have prior experience with indoor or outdoor exercise. Cows were involved in a crossover design experiment to evaluate the effects of the three management strategies. Within the experimental groups at each season, all groups of cows were balanced by parity (2.8 ± 0.56) and days in milk (125 ± 10). Subsequently, the cows were randomly assigned to each of the following treatments: (1) no exercise (cows were kept indoors and attached to their TSs); (2) indoor exercise [cows had access to an indoor pen (IP) providing 28 m^2 cow^{-1} for 1.5 h d^{-1}] and (3) outdoor exercise [cows had access to an outside nonaerated (OnAP) or aerated stand-off pad (OAP) providing 28 m^2 cow^{-1} for 1.5 h d^{-1}]. All groups of cows, either during winter or summer, had access to one of the housing treatments either in the morning (AM; 1.5 h) or in the afternoon (PM; 1.5 h). Each group of cows was subjected to treatment over a period of three consecutive weeks. Subsequently, a group of cows switched treatments randomly every 3 weeks until the completion of 9 weeks of evaluation.

All cows did not have access to fresh water and feed when they were in the exercise pens. This was done to simulate as closely as possible the real situation in commercial dairy barns. However, cows were fed *ad libitum* a total mixed ratio (TMR) twice daily (0900 and 1400 h) and provided with fresh water on their respective TSs all the time. The TMR was designed to fulfil the anticipated energy and nutrient needs of lactating dairy cows, following the guidelines outlined by the National Research Council (NRC, 2001). The formulation maintained consistent proportions and ingredients throughout the entire evaluation period, resulting in the following targeted chemical composition: 93 % organic matter, 16.5 % crude protein, 31.2 % neutral detergent fibre, 18.5 % acid detergent fibre, 28 % starch and 3.5 % total fat.

The solid concrete floor in the TSs in the CRSAD facility measured 1.81 m in length and 1.40 m in width and was covered with a 5-cm layer of wood shavings (grading: 2–5 mm; Pépinière St-Modeste, St-Modeste, Quebec, Canada). IP was created by temporarily removing the solid partition between two calving pens next to the TSs. The total area of the IP reached 28 m^2 (5.3 m × 5.3 m). Ten cm of straw (grading: 20–30 mm) was used as bedding on the concrete floor of the IP. Both OnAP and OAP were self-built next to the CRSAD dairy farm and had the same dimensions (28 m^2; 5.3 m × 5.3 m) as the IP. These stand-off pads (Fig. 1) comprised a top layer of 50 cm of cedar woodchips (grading: 10–25 mm; Pépinière St-Modeste) and a base layer of 350 mm of gravel (grading: 25 mm; S. Boudrias Inc., Laval, Quebec, Canada), placed over 10-cm drainage pipes, and a waterproof geotextile membrane (Dubois, Agrinova, Ontario, Canada). One of the outside exercise pens (OAP) was aerated using rigid 15-cm perforated PVC pipes (RONA, Lévis, Quebec,

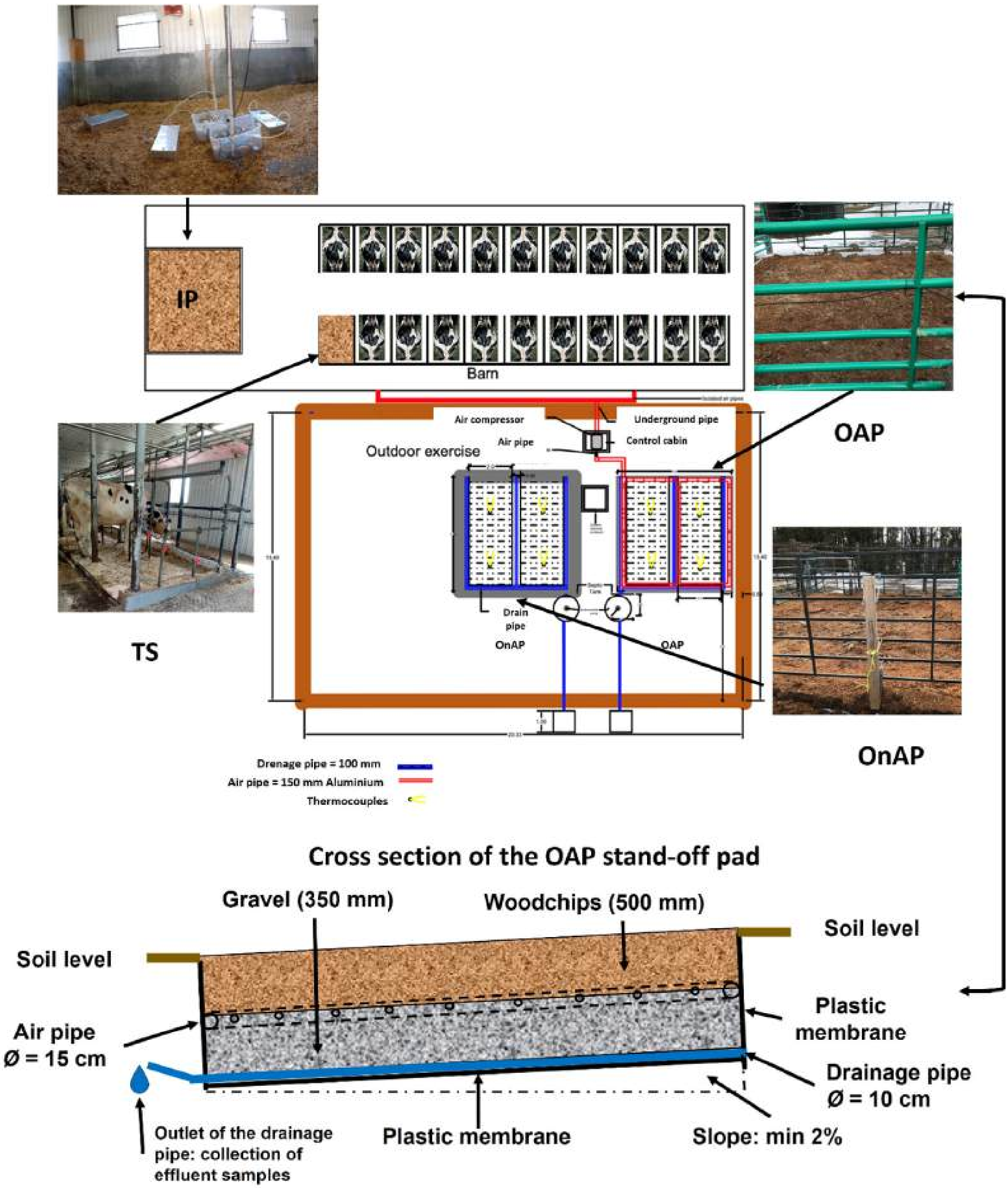

Fig. 1. Schematic view of the experimental site, setup and treatments: tie-stall (TSs), indoor exercise pen (IP) and outside nonaerated (OnAP) and aerated (OAP) pens. Cross-section of the OAP stand-off pad; for the OnAP stand-off pad, the air pipe was not installed.

Canada). The pipes contained 5-mm-diameter holes drilled at 0.2-m spacing on the top side. The air entering the OAP came from the exhaust fan on the wall of the adjacent barn (temperatures between 2 °C and 15 °C) at an airflow of 5.66 m^3 min^{-1} h^{-1}. In both OnAP and OAP, the temperature of the woodchip matrix was measured using eight thermocouples installed at four locations at two different depths (15 and 40 cm; Fig. 1).

The management of bedding for TS, IP, OnAP and OAP was similar in both seasons of evaluation. The straw bedding for IP remained there for the 9 weeks of evaluation, either in winter or summer. Every 2 weeks, another layer of 5 cm of straw was added to refresh the bedding. After the end of the winter period (9 weeks), the complete bedding was removed, and the IP was provided with another 10 cm of fresh bedding only before the beginning of the summer period. Subsequently, every 2 weeks, the bedding was refreshed, similar to that during the winter period. In both outdoor conditions (OnAP and OAP), bedding was refreshed every 2 weeks with a 5-cm layer of cedar woodchips. After the end of the winter evaluation, the bedding remained there, and before the summer period evaluation, 20 cm of cedar woodchips were added on top. The indoor beddings in TSs and IP were only humidified with the manure that was received when the cows were there during the day (2 × 1.5 h). In both outdoor conditions, bedding humidity was related to the manure received when cows were exercising (2 × 1.5 h), the snow received during winter and the amount of rain during summer. No follow-up was conducted for any of the bedding treatments to assess the long-term characteristics of the bedding materials.

2.2. Effluent sampling and analysis

A total of 1-L samples of both outdoor pen effluents were collected directly from the discharging pipe within the 500-L septic tanks (Fig. 1) when runoff events occurred (eight times in winter and five times in summer). However, the OnAP was frozen during the first 6 weeks of the winter phase; therefore, no effluent sample was collected for this treatment during this period. After collection, the sampling bottles were placed in a refrigerator at 4 °C before being transported in a cooler to Bureau Veritas (Quebec City, Quebec, Canada) or the IRDA laboratory (Quebec City) for analysis (Table 1). Contaminated water samples were analysed for microbiological properties (faecal and total coliforms) and physicochemical properties: pH, biological oxygen demand (BOD), chemical oxygen demand (COD), ammonium (NH_4–N), the sum of nitrates and nitrites ($NO_3 + NO_2$), suspended solids (SS) and total solids.

2.3. Gas sampling and analysis

Gas concentrations at every location (TS, IP, OnAP and OAP) during the summer season were determined using four dynamic stainless-steel chambers, as described by Hassouna et al. (2016); unfortunately, the equipment was not available during the winter period, and as such, no emissions were reported for the winter period. This technique allows the calculation of the emission rate by the linear increase in concentration over time per unit surface area covered by the chamber, which has been previously used to measure the gaseous emissions from outdoor concrete yards used by livestock (Misselbrook et al., 2001), emissions from bedding material (Misselbrook & Powell, 2005), evaluating the impact of crude protein manipulation in the diet of dairy cattle with NH_3 recovery by 97 % (Misselbrook et al., 2005a, 2005b) and determining NH_3 emissions from soil surfaces (Cabrera et al., 2001). Thus, the emissions results in the current study do not represent the entire system emissions from the bedding systems evaluated. The manure removal strategy applied in the present study was the most common strategy used by dairy farmers across the country. The manure in TSs was removed and placed in the gutter at the rear of the tie-stall. The manure within the gutter was removed twice a day (right after AM and PM milking) using a mechanical scraping system executed by the farm operator. The manure in the IP remained there for the entire evaluation season, either winter or summer. In both outdoor exercise areas (OnAP and OAP), the manure was not removed and remained there during the whole evaluation period (winter and summer). In all treatments, before placing the dynamic stainless-steel chamber, the surface was scrapped and homogenised to distribute the material and manure all over the surface and make gas measurement more representative. During the whole experiment in TS, the dynamic stainless-steel chamber was placed in the middle of the stall due to space limitations, and the gas was sampled while the cows were exercising (Fig. 2). The position of the dynamic stainless-steel chamber for IP, OnAP and OAP areas was randomly assigned, and gas measurements were performed without the animals in place.

Table 1
Analysis methods used in this study.

Parameter	Analysis method	Laboratory
pH	Electrometric method (multiparameter Hanna, Woonsocket, USA)	IRDA
Biological oxygen demand	Electrometric method	Bureau Veritas
Chemical oxygen demand	Closed reflux/colorimetry	Bureau Veritas
Nitrates and nitrites	Automated colorimetric method (Morse et al., 1994)	IRDA
Ammonium	Colorimetric technique	IRDA
Faecal and total coliforms	Membrane filtration	Bureau Veritas
Suspended solids	Gravimetric method	Bureau Veritas
Total solids	Gravimetric method	IRDA

Chambers were installed at a 10-cm depth in the bedding of all treatments. Each chamber was equipped with a closed-cell foam band to ensure an air-tight seal with the frame during deployment. All chambers were provided with a needle port on the top surface, which allowed the connection of a 20-mL syringe for air sampling. Gas samples were collected at intervals of 10 min during a 1-h period. During each interval, the syringe was filled four times, but only the latter sample was kept and released inside a negatively pressured 20-mL vial (Exetainer, Labco, High Wycombe, UK) and cooled at 4 °C for gas analysis within a 1-h period. Concentrations of carbon dioxide (CO_2) and GHGs, such as methane (CH_4) and N_2O, were determined by gas chromatography (GC; 6890 Series, Agilent, Montreal, Quebec, Canada) at the IRDA laboratory. Briefly, gas samples underwent two injections during the analysis. The initial injection, intended for determining CO_2 and CH_4, involved injecting 100 μL into an analytical column (Haysep-Q, 80–100 mesh; 3.65 m × 4.7625 mm, Restek, Canada) with nitrogen as the carrier gas flowing at 2 mL min^{-1} through a 6.5-min injection loop. Prior to sample analysis, the GC equipment was calibrated using a certified calibration gas mixture (1:1 CO_2 and CH_4; BOC GAZ, Canada). The GC column temperature was maintained at a constant temperature of 60 °C. During the 6.5-min injection period, the carrier gas emerged in the first minute, followed by CO_2 at 2.5 min and CH_4 at 4.25 min. The second injection, meant for determining N_2O, involved injecting a 100-μL gas sample into an analytical column Rt-Q-bond (30 m × 0.25 mm i. d., 8-μm film,

Fig. 2. Gas sampling is performed in closed chambers for greenhouse gases (four boxes in the back) and by the bubbling method for ammonia (two containers in the front) in tie-stalls.

Restek) with argon as the carrier gas at a flow rate of 0.9 mL min^{-1} through a 6-min injection loop. The GC injector temperature was initially maintained at 60 °C for 4 min, then increased to 100 °C at the end of the injection loop. Under these conditions, the N_2O peak was observed at 3.42 min.

NH_3 emissions were determined using the bubbling acid trap method, as described by Hassouna et al. (2016). One end of each stainless-steel chamber was connected to a sulfuric acid solution (H_2SO_4; 0.54 M) trap with 6-mm tubing. Subsequently, air from the box was pumped inside the trap at a flow rate of 1 L h^{-1}. This flow rate was adjusted at the beginning of the sampling and at 20-min intervals between samples. NH_4–N was captured in a sulfuric acid solution composed of 500 mL of water and 1.4 mL of freshly prepared H_2SO_4. Briefly, as NH_3 is directed through the acid-trapping solution, it counteracts a portion of the acid present. The trap system's sufficient acid stoichiometric capacity becomes essential to guarantee the complete absorption of all NH_3 in the sampled air without entirely neutralising the acid. To illustrate, in the case of using a sulfuric acid solution within the trap, according to the stoichiometry, 1 mol of the acid has the capability to entirely capture 2 mol of NH_3, as depicted in the subsequent equation: $H_2SO_4 + 2NH_3 = >(NH_4)_2\,SO_4$. Finally, the determination of NH_4–N was assessed using a colorimetric technique. In general, colorimetric methods are used to determine lower concentrations of NH_3 in solutions (~2 mg L^{-1}) and then the NH_3 concentration was calculated by stoichiometry as described by Ndegwa et al. (2009).

2.4. Statistical analysis

Data were analysed using a multivariate time series analysis comparing the mean of all variables within the season (summer vs. winter), which has been described as suitable for analysing environmental monitoring data (Zhang et al., 2018). For this, we used the PERMANOVA procedure of SAS version 9.4 (SAS Institute Inc., Cary, NC, USA). Water effluent composition was analysed in two different seasons (winter and summer) with two treatments (OnAP vs. OAP) in each season. Statistical differences across the season, treatment and their interactions were evaluated and are indicated in the figures. Data on faecal and total coliform effluent concentrations were naturally Log transformed before statistical analysis. Data on gas emissions (NH_3, CO_2, CH_4 and N_2O) across four different housing treatments (TS, IP, OnAP and OAP) were only reported during the summer season; thus, no effect of the season is reported for gas emissions. All mean statistical differences across treatments and seasons were assessed by the Bonferroni test approach, which uses a series of t-tests but corrects the significance level for multiple testing by dividing the significance levels by the number of tests being performed because it reduces the chances of a Type I error occurring. Significance and tendencies were declared at $P < 0.05$ and $P < 0.10$, respectively, for the main effects. A mixed-model regression analysis was performed to examine, during summer, the relationship between ambient temperature and gas emissions recorded in the bedding of outdoor exercise areas, specifically in both the OnAP and OAP. For this analysis, emissions from indoor treatments were not considered. This exclusion was based on the understanding that ambient temperature might not exert the same influence under indoor conditions.

3. Results

3.1. Effluent characteristics and bedding temperature

3.1.1. Physicochemical properties of leachates

The effluent concentration was affected by season (summer vs. winter) for BOD, COD, pH, NH_4–N and $NO_3 + NO_2$ ($P < 0.05$). A higher BOD was recorded in the winter effluent (+89 %; $P_{season} < 0.001$; Fig. 3A), with a higher level for OAP than for OnAP (160 vs. 81 mg L^{-1}, respectively; $P_{treatment} = 0.01$; Fig. 3A). In contrast, COD in the summer period was 74 % higher than that in the winter period ($P_{season} = 0.02$; Fig. 3B). In both seasons, OAP had higher COD values (1729 and 2620 mg L^{-1}, respectively) than OnAP ($P_{treatment} = 0.02$; Fig. 3B). The concentration of SS did not differ across treatments or seasons ($P > 0.05$; Fig. 3C), indicating high variability across measurements. No season effect was observed for total solids ($P_{season} > 0.05$; Fig. 3D), whereas OAP in both seasons presented a higher concentration than OnAP (1594 vs. 821 mg L^{-1} for winter and 2829 vs. 2217 mg L^{-1} for summer, respectively; $P_{treatment} = 0.02$; Fig. 3D).

The effluent NH_4–N concentration was higher during winter by 96 % than during summer ($P_{season} < 0.01$; Fig. 3E). However, no differences were found between treatments in both seasons ($P > 0.05$; Fig. 3E). In contrast, NO_3+NO_2 concentration was higher in the summer effluent (85 mg L^{-1}) than in the winter effluent (4 mg L^{-1}) ($P_{season} < 0.001$; Fig. 3F). However, in both seasons, no statistical differences were observed across treatments ($P > 0.05$; Fig. 3F). During winter, the effluent presented a higher pH than that during summer (7.4 vs. 6.9; $P_{season} = 0.01$; Fig. 3G). Across treatments, pH did not differ significantly during winter (7.3 vs. 7.6 for OAP and OnAP, respectively; Fig. 3G), but during summer, a higher pH was observed for OAP (7.2) than for OnAP (6.7) ($P_{treatment} = 0.01$; Fig. 3G).

BOD over time across treatments differed in the effluent collected during winter, more specifically in the last 2 weeks of measurement (4th week of March and 2 nd week of April). OnAP showed a lower BOD than OAP (26.5 vs. 170 mg L^{-1}, respectively; $P_{treatment} = 0.01$; Fig. 4A) during winter, whereas a constant BOD over time was observed in the summer effluent without differences between treatments ($P > 0.05$; Fig. 4B). Effluent COD during winter was generally lower after the 3rd week of March until the 2 nd week of April in OnAP (overall mean of 553 mg L^{-1}) than in OAP (overall mean of 1200 mg L^{-1}; $P_{treatment} = 0.03$; Fig. 4C). During summer, COD decreased over time in both treatments, but OAP presented a higher concentration at every time point than OnAP (overall mean: 2620 vs. 1340 mg L^{-1}, respectively, $P_{treatment} = 0.01$; Fig. 4D).

During winter, SS was higher for OnAP than for OAP during the 3rd and 4th weeks of March, but their concentration was deeply decreased from 160 to 4 mg L^{-1} by the 2 nd week of April ($P_{treatment} = 0.01$; Fig. 4E). During summer, SS in OnAP increased by 63 % only in the 3rd week of August compared to that in OAP ($P_{treatment} = 0.03$; Fig. 4F), but SS presented a stable concentration over time in both treatments (Fig. 4F). During the winter conditions, the total solids concentration was measured only three times at the end of the winter experimental phase. Nevertheless, an increase in the total solid concentration was observed for OAP during the 4th week of March (2239 vs. 449 mg L^{-1} for OnAP; $P_{treatment} = 0.02$; Fig. 4G). The total solids concentration in the effluent during summer only differed between treatments at the first sampling time (4th week of July; Fig. 4H), whereas OAP showed a higher total solids concentration of 3600 mg L^{-1} than OnAP 2311 mg L^{-1} ($P_{treatment} = 0.04$; Fig. 4H).

The effluent pH during winter increased over time in OAP until the end of March, from 6.7 to 7.9, then decreased to 7.1 b y April, which was the end of the winter season (Fig. 4I). In addition, both OAP and OnAP treatments during winter showed similar pH values. In the case of OnAP, although it was only possible to have effluent samples to measure the pH by the end of the winter session (end of March and beginning of April), the pH values for OnAP were as high (7.6) as those for OAP during the same period ($P_{treatment} > 0.05$; Fig. 4I). During summer, the effluent pH was generally higher for OAP, and this increment was predominant during August (overall pH mean of August = 7.2; $P_{treatment} < 0.01$; Fig. 4J), compared to OnAP (overall pH mean of August = 6.5; $P_{treatment} < 0.01$; Fig. 4J).

3.1.2. Microbiological properties of leachates

Faecal coliforms for OnAP and total coliform concentrations for OAP and OnAP in the effluent were higher during winter ($P_{season} < 0.001$; Fig. 5A and B), especially for OnAP (5.02 Log CFU 100 mL^{-1} vs. 2.03 Log CFU 100 mL^{-1} for OAP; $P_{treatment} = 0.01$; Fig. 5A).

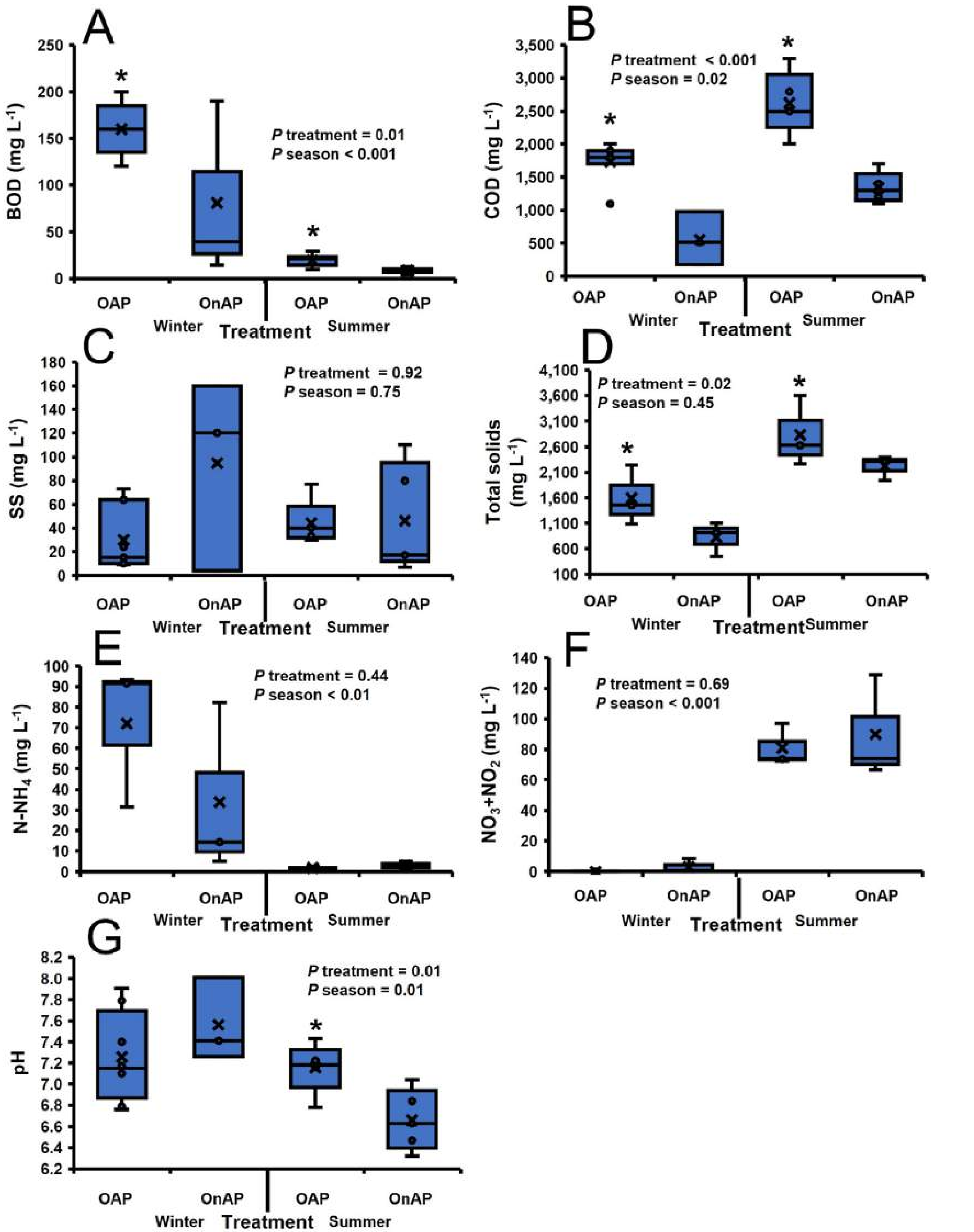

Fig. 3. Effect of an outside exercise pen, either nonaerated (OnAP) or aerated (OAP), under two different seasons on effluent physicochemical properties: (A) biological oxygen demand (BOD); (B) chemical oxygen demand (COD); (C) suspended solids (SS); (D) total solids; (E) ammonium (NH_4–N); (F) sum of nitrates and nitrites (NO_3+NO_2) and (G) pH. *Statistical differences between treatments within the season are indicated by $P < 0.05$.

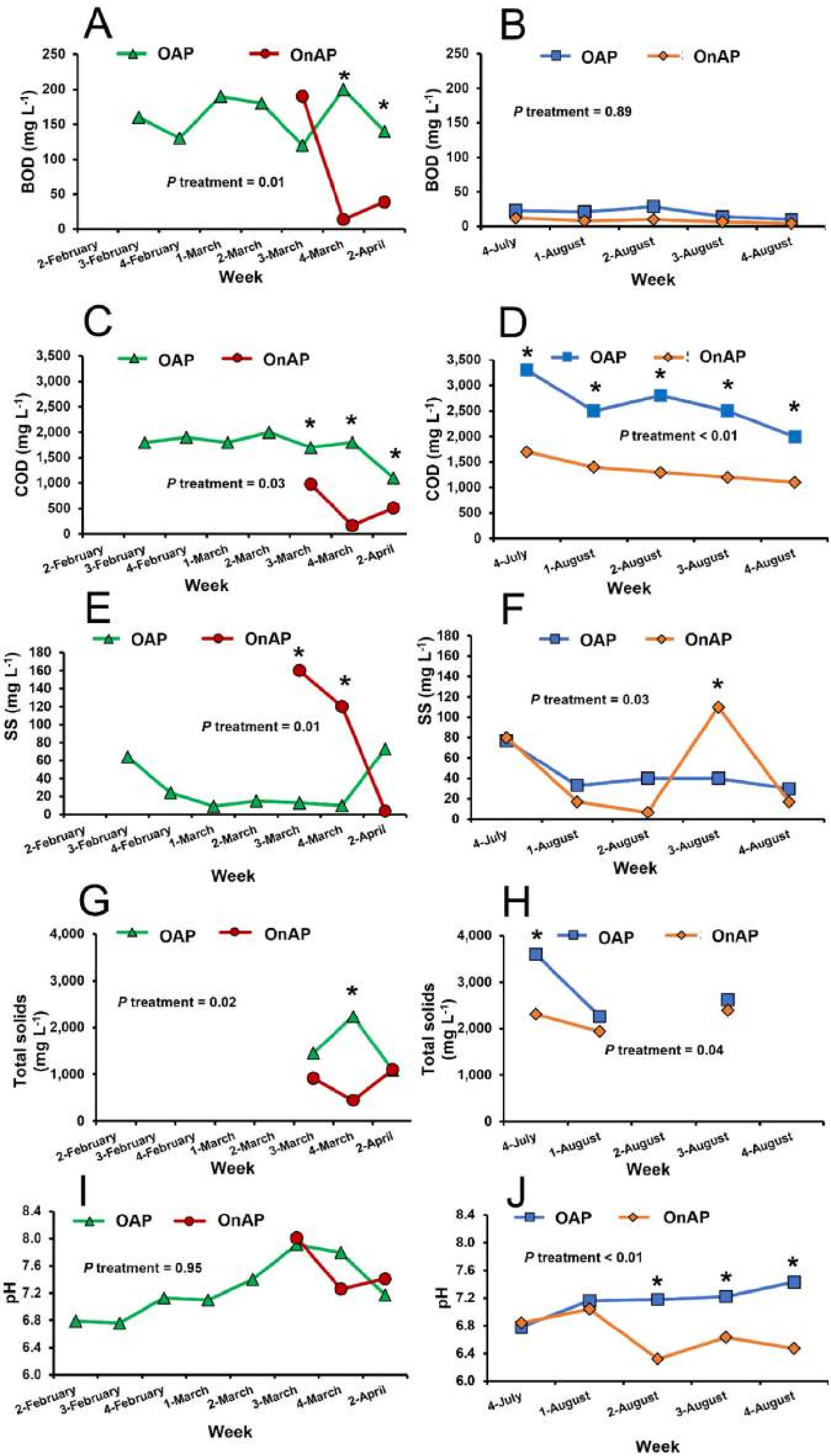

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Fig. 4. Effect of an outside exercise pen, either nonaerated (OnAP) or aerated (OAP), under two different seasons, winter (left) and summer (right), on time course effluent properties: biological oxygen demand (BOD; A and B), chemical oxygen demand (COD; C and D), suspended solids (SS; E and F), total solids (G and H) and pH (I and J). *Statistical differences between treatments within the season are indicated by $P < 0.05$. Weeks on the X-axis indicate the number of experimental weeks in each month.

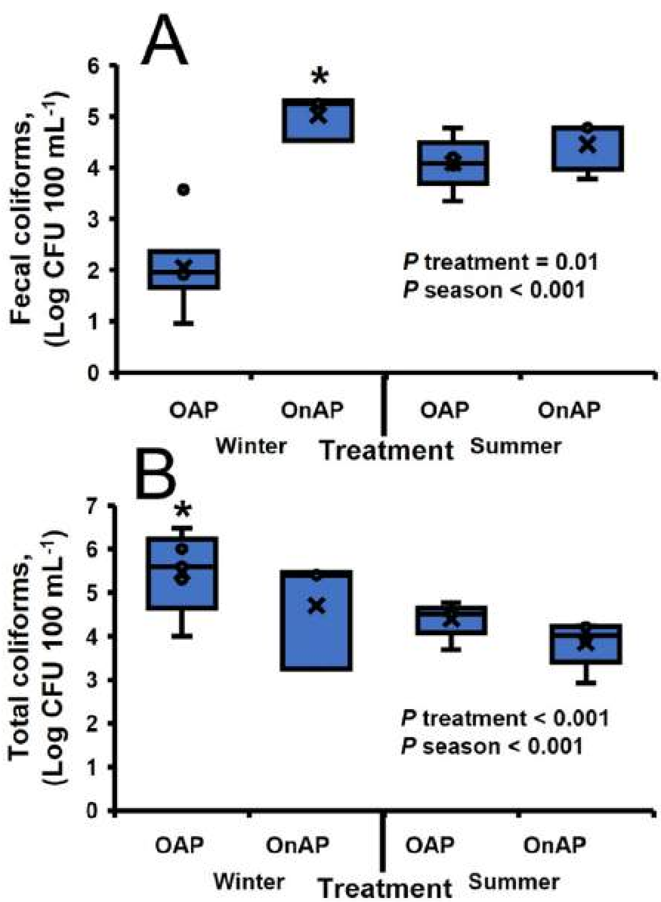


Fig. 5. Effect of an outside exercise pen, either nonaerated (OnAP) or aerated (OAP), under two different seasons on the overall effluent concentration of (A) Log faecal coliforms and (B) Log total coliforms. *Statistical differences between treatments within the season are indicated by $P < 0.05$.

During winter, faecal coliform concentrations over time was higher on the 4th week of March for OnAP (5.30 Log CFU 100 mL^{-1}) than for OnAP (1.95 Log CFU 100 mL^{-1}) ($P_{treatment} < 0.01$; Fig. 6A). However, on the last week of sampling (2 nd week of April), faecal concentration for OAP decreased to 2.34 Log CFU 100 mL^{-1}, and OnAP showed a higher concentration (3.56 Log CFU 100 mL^{-1}; $P_{treatment} < 0.01$; Fig. 6A). During the summer conditions, effluent faecal coliform concentrations for both OAP and OnAP showed a higher increase over time. From the 1st to the 2 nd week of August, this increased from 3.77 to 4.78 Log CFU 100 mL^{-1}, and concentration of OnAP remains at this high level until the end of the summer phase (4.78 Log CFU 100 mL^{-1}; P treatment <0.001; Fig. 6B), whereas faecal concentration of OAP after the 2 nd week of August was reduced sharply until the end of the summer phase (3.34 Log CFU 100 mL^{-1}; $P > 0.05$; Fig. 6B).

During winter, the total coliform concentration in the effluent increases over time from the 1st to the 4th week of March for OAP compared to OnAP. During this last week, OAP presented the greatest concentration (6.02 Log CFU 100 mL^{-1}), although the concentration was reduced considerably for this treatment in the last week of winter sampling (4.47 Log CFU 100 mL^{-1}; Fig. 6C). The lowest total coliform concentration was shown in the effluent from 4 March for OnAP (0.95 Log CFU 100 mL^{-1}; Fig. 6C). The total coliform concentration in the summer effluent was higher in OAP from the 4th week of July to the 3rd of August (overall mean: 4.56 Log CFU 100 mL^{-1}; Fig. 6D) than in OnAP (3.96 Log CFU 100 mL^{-1}; $P_{treatment} < 0.001$; Fig. 6D). Subsequently, no differences were noticed between both treatments (Fig. 6D).

3.1.3. Pad temperature

During winter, the temperature registered in OAP_base was above the freezing point (+1.3 °C), relative to the temperatures registered in OAP_top, OnAP_top and OnAP_base and ambient temperature (−2.3 °C, −3.3 °C, −0.9 °C and −2.8 °C, respectively; $P_{treatment} = 0.03$; Fig. 7A). Aeration appeared to increase the base temperature of the bedding during winter above the freezing temperature. Overall, the lowest temperatures recorded in the bedding of the stand-off pad were recorded during February for the top layer of OAP, OnAP and ambient (overall average by week during February: −4.7 °C, −6.8 °C and −7.4 °C, respectively; $P_{treatment} = 0.02$; Fig. 7B). The temperature recorded at the base of the woodchip layer (40 cm deep) during the summer period was 2.4 °C and 1.8 °C lower than that recorded at the top (15 cm deep) in OAP and OnAP, respectively ($P_{treatment} = 0.02$; Fig. 7C). It was also noticed that bed aeration reduced the overall temperature by 2.2 °C for OAP relative to OnAP ($P_{treatment} = 0.02$; Fig. 7C). The ambient summer temperature was lower (22.3 °C) than the temperatures recorded for both OAP (23.6 °C) and OnAP (28.8 °C), respectively ($P_{treatment} = 0.02$; Fig. 7A). Both stand-off pads presented temperature differences during the whole month of July, but in August, temperatures were similar across treatments (Fig. 7D). Ambient temperature in summer did not influence the temperature recorded from the base and top of both treatments, as the ambient temperature appears to be approximately 10 °C lower during August ($P_{treatment} = 0.01$; Fig. 7D).

3.2. Gas emissions

3.2.1. Carbon dioxide

Emissions of CO_2 were higher in both outdoor conditions (OAP and OnAP; $P_{treatment} < 0.01$; Fig. 8A) than in both indoor treatments, IP and TSs (1,697, 1,900, 429 and 258 mg m^2 h^{-1}, respectively; Fig. 8A). However, when looking over time, CO_2 emissions for both outdoor treatments were generally higher after measurements by the end of July to the end of the summer season (August; $P_{treatment} < 0.01$; Fig. 8B). In addition, in both indoor treatments, CO_2 emissions were constant throughout the summer measurements ($P_{treatment} < 0.01$; Fig. 8B).

3.2.2. Methane

Indoor treatments resulted in higher CH_4 emissions (2.9 mg^{-1} m^2 h^{-1} for IP and 2.8 mg^{-1} m^2 h^{-1} for TS; $P_{treatment} < 0.01$; Fig. 9A) than both outdoor exercise pens (1.0 mg^{-1} m^2 h^{-1} for OAP and 0.6 mg^{-1} m^2 h^{-1} for OnAP; Fig. 9A). However, the overall increment in both indoor housing systems was related to an increment in emissions at the beginning (measurements during July) and end (measurements during the last 2 weeks of August) of the summer period ($P_{treatment} < 0.01$; Fig. 9B).

3.2.3. Nitrous oxide

Overall emission of N_2O was higher in OnAP (2.18 mg^{-1} m^2 h^{-1}) than in OAP and both indoor treatments, namely, IP and TSs ($P_{treatment} <$ 0.001; Fig. 10A). This high overall N_2O emission for OnAP was related to an increase in emissions during the 3rd and 4th weeks of July, with emissions of approximately 6.3 and 8.0 mg^{-1} m^2 h^{-1}, respectively ($P_{treatment} < 0.001$; Fig. 10B). Subsequently, N_2O emissions exhibited a sharp decrease and remained low with no differences between

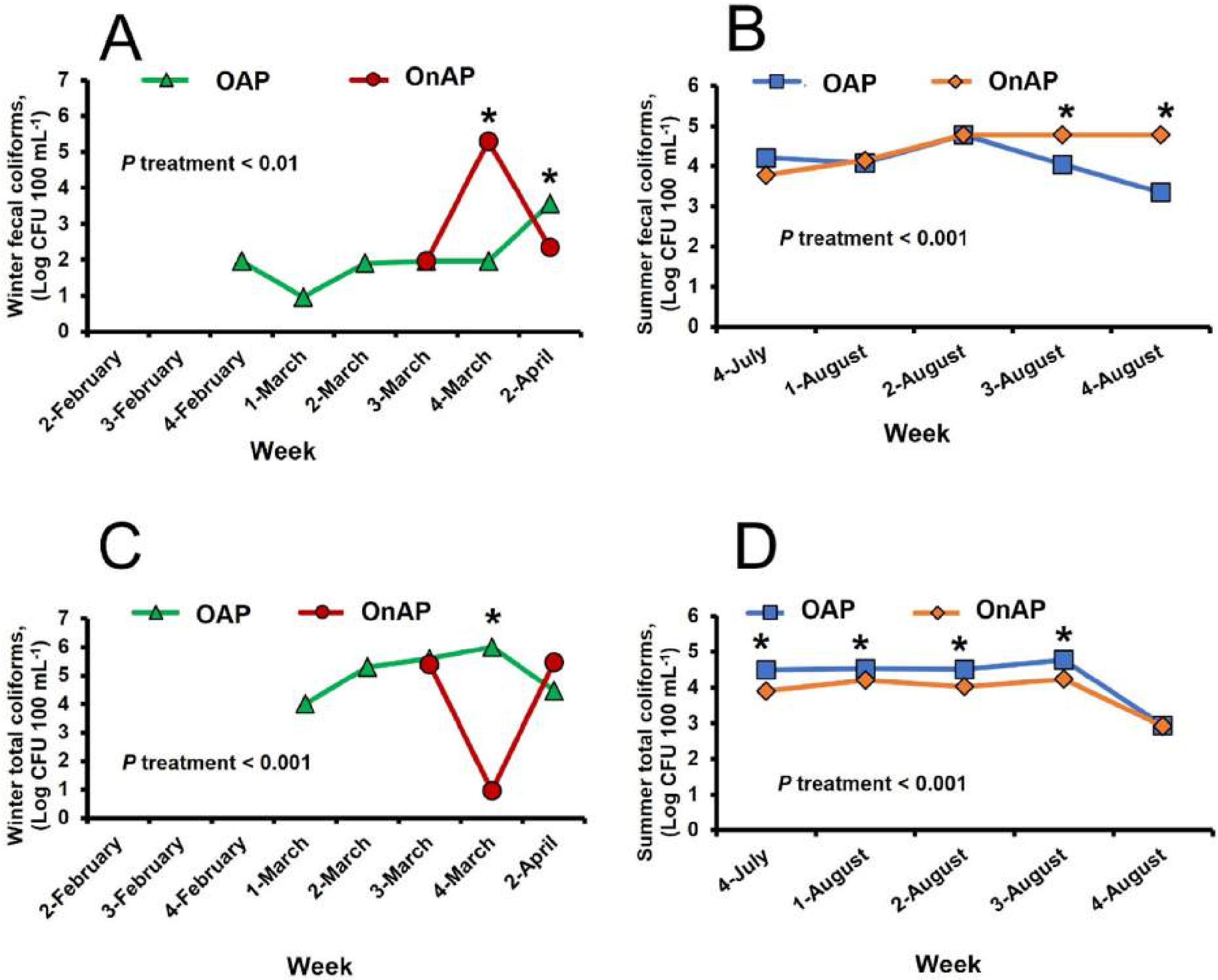


Fig. 6. Effect of an outside exercise pen, either nonaerated (OnAP) or aerated (OAP), under two different seasons on the time course effluent concentration of Log faecal coliforms during winter (A) or summer (B) and Log total coliforms during winter (C) or summer (D). *Statistical differences between treatments within the season are indicated by $P < 0.05$. Weeks on the X-axis indicate the number of experimental weeks in each month.

treatments (Fig. 10B).

3.2.4. Ammonia

Overall NH_3 emissions did not differ across treatments ($P_{treatment} > 0.05$; Fig. 11A). NH_3 emissions reached 0.29, 0.42, 0.88 and 0.44 mg^{-1} m^2 h^{-1} for OAP, OnAP, IP and TS, respectively (Fig. 11A). However, a peak for NH_3 emissions was observed during the 1st week of August for the IP treatment, which differed significantly from the three other treatments ($P_{treatment} = 0.01$; Fig. 11B). Subsequently, NH_3 emissions remained low initially, with no differences between treatments (Fig. 11A and B).

3.2.5. Association between ambient temperature and emissions

Parameter estimates for the mixed-model regression lines are shown in Fig. 12. Ambient temperature was positively associated with CO_2 (r = 0.92), CH_4 (r = 0.64), N_2O (r = 0.48) and NH_3 (r = 0.75) bedding emissions in both outdoor exercise areas (OnAP and OAP).

4. Discussion

4.1. Effluent properties

Evaluation of the dairy cow's effluent deserves special attention because its levels of potential contaminants typically exceed those considered hazardous for domestic wastewater (Meul et al., 2009); therefore, strategies to reduce these compounds before effluents are incorporated into the soil are needed. Usually, effluent from livestock presents large quantities of nutrients, sediments and BOD (Schaafsma et al., 1999). Schaafsma et al. (1999) reported that the effluent of a dairy barn presents the following composition: 1914 ± 292 mg L^{-1} BOD; 1645 ± 534 mg L^{-1} SS; 5.51 ± 1.6 mg L^{-1} NO_2 and 71.71 ± 13.3 mg L^{-1} NH_4–N. Concentrations of BOD and SS in the previous study are 10 times higher than those presented in the current study for winter conditions. In addition, those levels are well above the proposed limit for wastewater in the Quebec region (25 mg^{-1} m^3; MELCC, 2020). The lower concentration reported here relative to the literature may be related to the time that dairy cows spent in the outdoor exercise area (3 h d^{-1}). Thus, considering that an average 650 kg lactating dairy cow urinates 8.25 times a day (Nennich et al., 2005), producing a total of 23.1 L^{-1} d^{-1} of

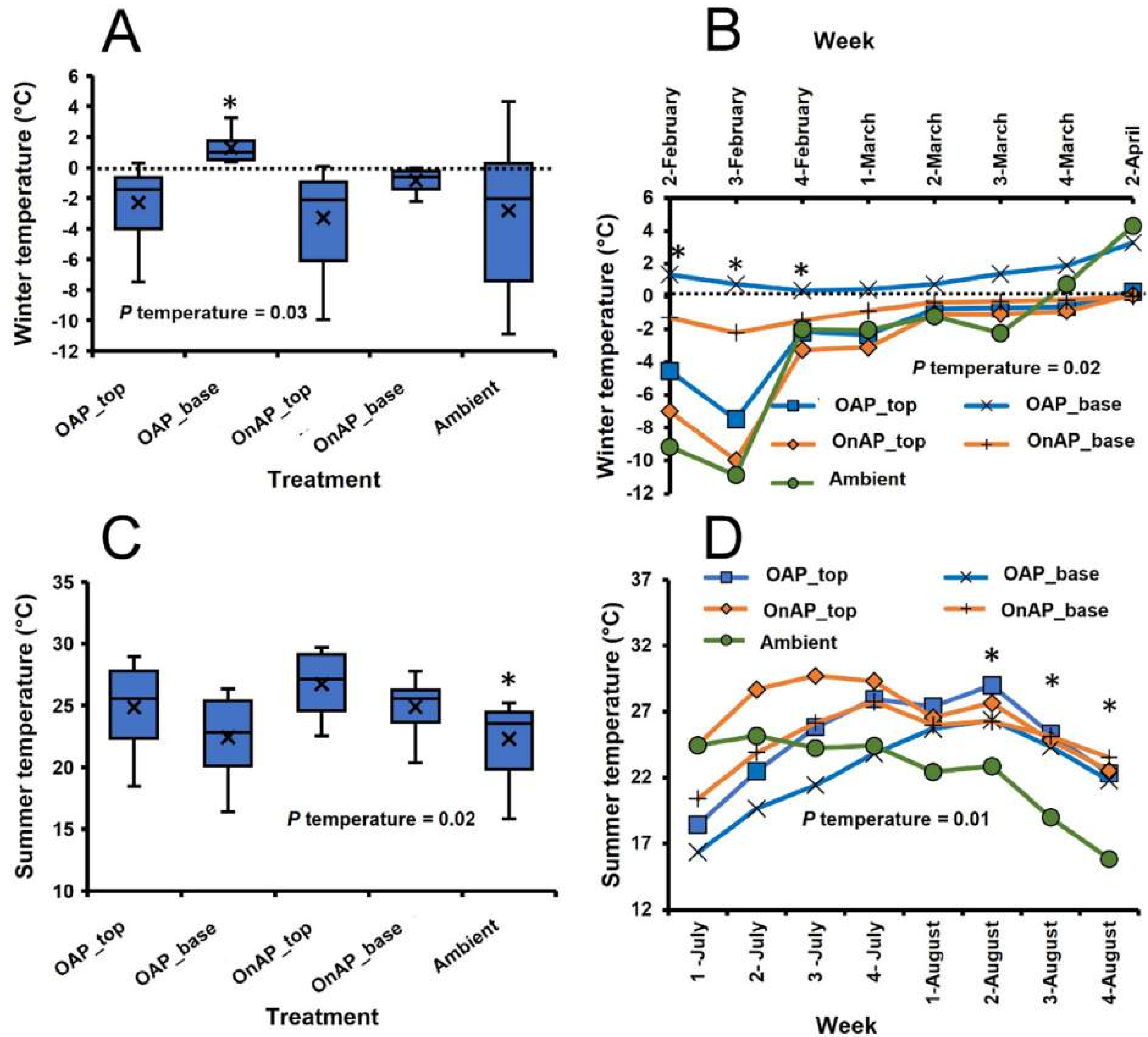


Fig. 7. Overall and time course winter (A and B) and summer (C and D) bed and ambient temperatures of an outside exercise pen, either nonaerated (OnAP) or aerated (OAP), at two different depths (base and top). *Statistical differences between treatments within the season are indicated by $P < 0.05$. Weeks on the X-axis for B and D indicate the number of experimental weeks in each month.

urine, and defecates 12.25 times a day, producing a total of 66.3 kg^{-1} d^{-1} of faeces (Nennich et al., 2005), adapting the previous urine and faeces estimation over 24 h^{-1} of a cow under the current study conditions, over a period of 1.5 h^{-1} a cow can produce 1.44 L^{-1} of urine and 4.14 kg^{-1} of faeces. In the current study, cows were placed in our housing treatments twice a day, AM and PM (2 times 1.5 h^{-1}). Therefore, it is expected to be 2.89 L d^{-1} of urine and 8.29 kg d^{-1} of faeces. This estimation shows that over a period of 9 weeks, under the conditions of this study, 130 L of urine and 373 kg of faeces can be expected. This scenario was reproduced twice in winter and summer; the previous quantities needed to be doubled: 260 L of urine and 746 kg of faeces. With this manure extrapolation from the current study, it can be noticed that the total manure amounts were not that high compared to the amount that can be collected in a barn when cows are housed 24 h d^{-1}. This can explain why the composition results presented here are higher than the composition of liquid effluent reported by Schaafsma et al. (1999), which refers to samples collected in the effluent of a dairy barn of 170 dairy cows housed continuously. A similar observation has also been reported by other studies (Alalam et al., 2021; Meul et al., 2009).

The results indicated that the effluent properties of outside exercise areas differ across seasons. Higher levels of BOD, pH, NH_4–N, faecal and total coliforms were noted in the winter effluent. This may be related to the low temperatures, predominantly observed in OnAP, which promoted freezing conditions (February to the beginning of March), which did not allow time sampling of effluent during this period. Thus, a slowly increased accumulation of such effluent compounds during winter could have been expected, and a slow release in the effluent by the end of winter during the melting process could have occurred, increasing the concentration of BOD, NH_4–N, faecal and total coliforms in the collected effluent. Variation throughout the year in the dairy cow wastewater composition has also been reported by another study (Skoczko et al., 2017), evaluating a mixture of effluent from domestic and dairy

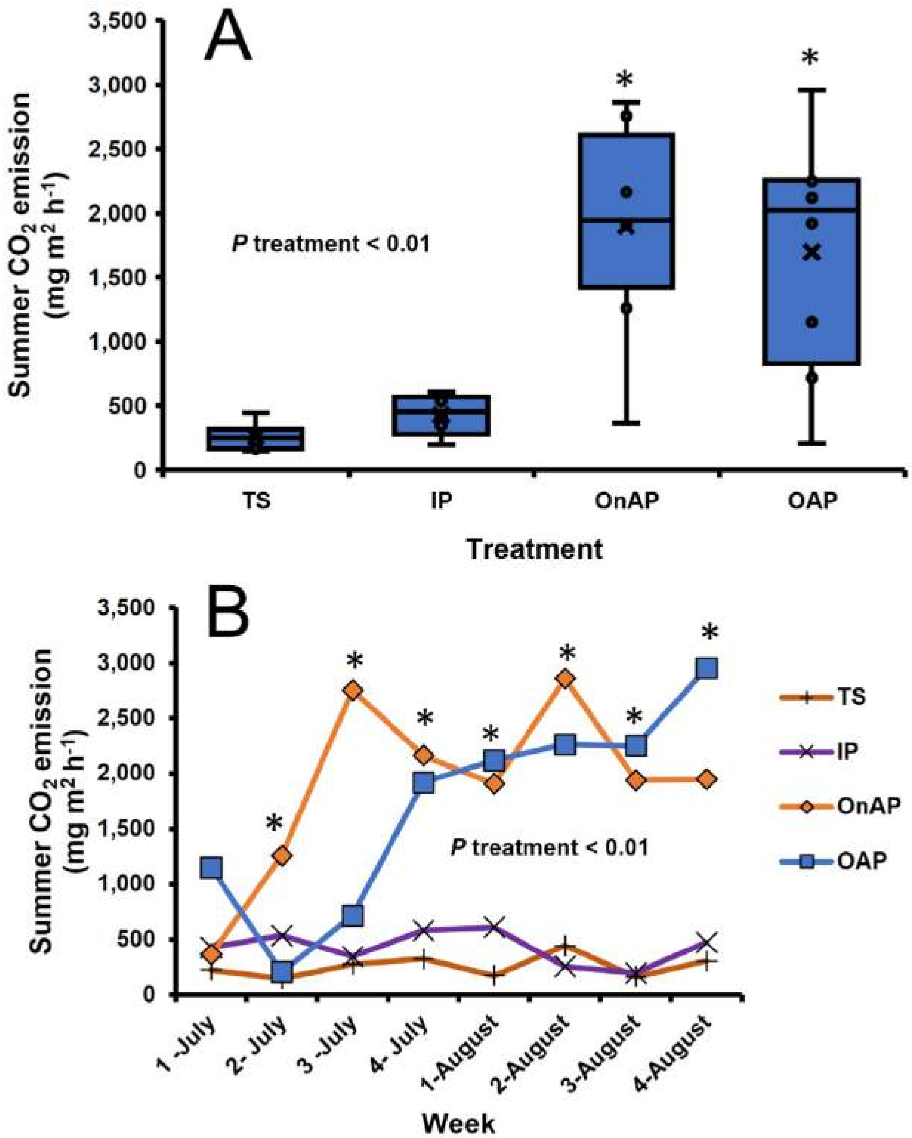


Fig. 8. Effect of indoor tie-stalls (TSs), an indoor pen (IP) and an outside exercise pen, either nonaerated (OnAP) or aerated (OAP), during the summer conditions on overall (A) and time course (B) CO_2 emissions. *Statistically different ($P < 0.05$). Weeks on the X-axis for B indicate the number of experimental weeks in each month.

wastewater and noneffluent collected from a dairy cow exercise area. The authors reported that BOD, COD and total nitrogen removal efficiency were lower in winter than in the other seasons of the year. In addition, the study of Skoczko et al. (2017) was performed in North Poland, where the winter temperature does not go lower than −5 °C, compared to the winter temperature in the province of Quebec, which can be lower than −20 °C during several days. This might suggest that ambient temperature could play an important role in effluent parameters, as observed in the current study.

Differences in the ambient temperature between both summer and winter seasons could explain the high concentration of coliforms in the effluent during winter relative to summer, except for the faecal coliform concentration in OAP. In addition, providing aeration to the outdoor exercise area during summer and winter in the present study showed an increase in the physicochemical properties of the effluent (BOD, COD, total solids and pH). This contrasts with a previous report, where aeration reduced up to 99 % of the biodegradable organic matter and 98 % of total solids in swine manure (Garzón-Zuñiga et al., 2007). Previous studies found this effect at an aeration rate of 3.4 m^3 m^2 h^{-1}, which was lower than that at the aeration rate implemented in the current study (5.6 m^3 m^2 h^{-1}). In addition, the aeration system implemented in the current study for OAP was warm airflow from a dairy cow's barn, which continuously melted the snow during the winter season. This increased the flow of water through the pad during winter when degradation is not optimal. Second, we observed that the drainage pipes cause holes in the woodchip matrix caused by well-defined preferential air paths. All these issues might have decreased the oxidation process efficiency of the aeration pad in the current study. However, the aeration rate used in the OAP treatment during the winter period has influenced the proliferation of faecal coliforms by increasing the temperature in the bedding. Nevertheless, aeration has been suggested to be used as a sterilisation strategy in bedding and manure materials at optimal temperature conditions (20 °C) (Guryanov et al., 2021). In addition, factors such as temperature, solar intensity and pH could influence the rate of decay or proliferation of coliforms (Auer & Niehaus, 1993; Howell et al., 1996; Mayo, 1989). For example, high temperatures were shown to lower the survival rate or increase the decay rate of coliforms (Flint, 1987; Howell et al., 1996). Thus, the higher ambient temperatures during summer may explain the faecal and total coliform reductions relative to winter conditions. This reduction could be explained by a slowed-down bacterial metabolism rate at low temperatures during the winter season (Lessard & Sieburth, 1983; Mezrioui et al., 1995). Furthermore, solar

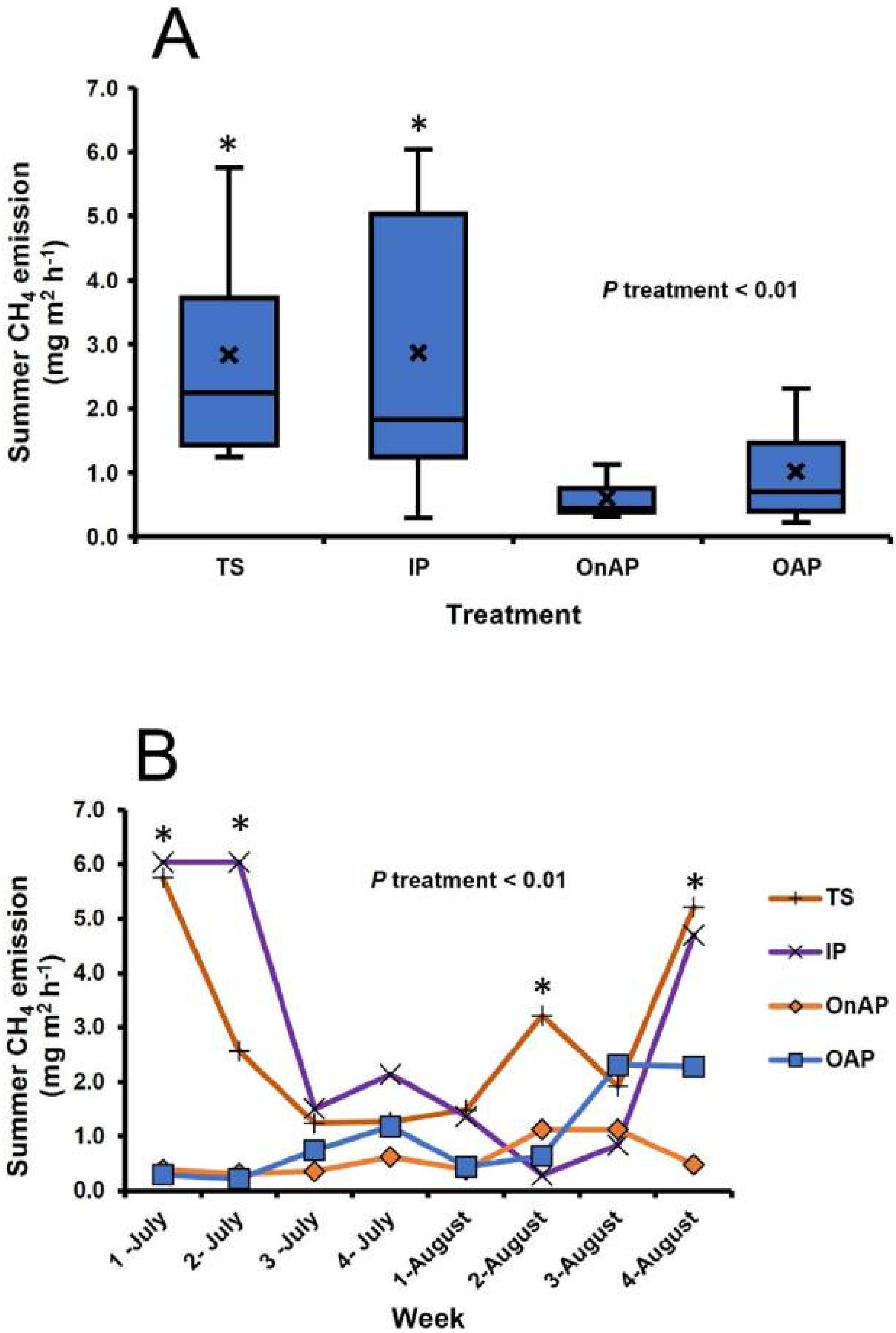


Fig. 9. Effect of indoor tie-stalls (TSs), an indoor pen (IP) and an outside exercise pen, either nonaerated (OnAP) or aerated (OAP), during the summer conditions on overall (A) and time course (B) CH_4 emissions. *Statistically different ($P < 0.05$). Weeks on the X-axis for B indicate the number of experimental weeks in each month.

intensity is higher during summer than during winter. Since coliforms are a group of bacteria sensitive to solar radiation, they are more susceptible to the activities of microbial predators (Chamberlin, 1978). Solar radiation may affect the cytoplasmic membrane and DNA, whereas UV radiation could make coliforms more sensitive to pH changes (Curtis et al., 1992). Mayo (1995) showed that the faecal coliform decay rate coefficient increases with increasing pH (pH > 7.0). However, the correlation was poor (R = 0.27), suggesting that factors other than pH might play a major role in coliform reduction. The present study also aligns with this finding, as the effluent pH was generally higher than 7.0 during winter, where a higher faecal and total coliform concentration was reported. Although aeration may lower faecal coliform concentrations during winter in OAP, we did not observe a consistent response to the air injection because the total coliform concentration in OAP was higher than that in OnAP.

4.2. *Gas emissions*

The proposed outdoor exercise areas reduce CH_4 emissions during summer. This may be related to the higher aerobic conditions in the outdoor systems than in the indoor systems, whereas the indoor systems in the current study were surrounded by obstacles, which could limit aeration. Nevertheless, aerobic conditions favour CO_2 production instead of CH_4 (Lopez-Real & Baptista, 1996). The aerobic condition preferred at the outdoor exercise areas could explain the higher CO_2 emissions in both OnAP and OAP treatments than in both indoor

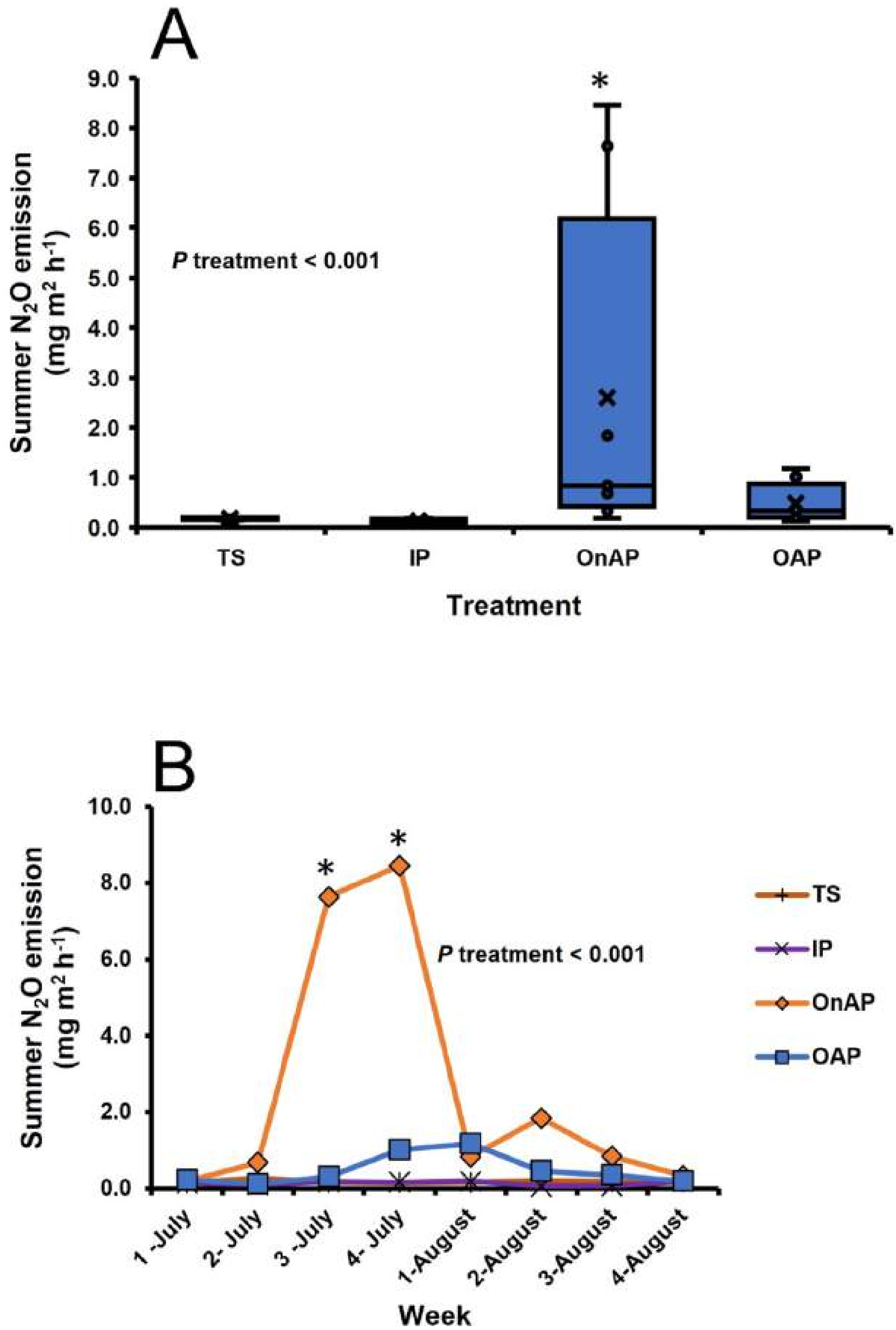


Fig. 10. Effect of indoor tie-stalls (TSs), an indoor pen (IP) and an outside exercise pen, either nonaerated (OnAP) or aerated (OAP), during the summer conditions on overall (A) and time course (B) N_2O emissions. *Statistically different ($P < 0.05$). Weeks on the X-axis for B indicate the number of experimental weeks in each month.

treatments IP and TS. Nevertheless, the higher CO_2 emissions observed in both outdoor conditions could also be explained by the CO_2 produced by cow respiration, as OAP was aerated with the exhaust air from the cow's barn. In addition, it could be suggested that manure accumulation in the bedding in both OnAP and OAP may stimulate CO_2 emissions from composted or stockpiled dairy cattle manure, which is usually higher than other manure management systems, e.g. slurry emissions (Pattey et al., 2005). In addition, a positive association was observed between the ambient temperature and bedding gas emissions for both outdoor conditions (OnAP and OAP) because elevated summer ambient temperatures stimulated CO_2, CH_4, N_2O and NH_3 emissions in the current study. It has been reported that during summer conditions, farm manure CO_2 emissions are higher than seasonal temperatures below 4 °C (Sneath et al., 2006). Summer temperatures may increase organic matter fermentation and oxidation of organic compounds relative to temperatures below 4 °C (Sneath et al., 2006). However, we observed that during the summer conditions, there was higher CH_4 with low CO_2 emissions in both indoor conditions (IP and TSs) than in both outdoor areas. The lower CH_4 emissions under both outdoor conditions (OnAP and OAP) could suggest that the presence of bedding materials might influence emissions. Chamberlin (1978) reported that emissions from cattle housing are reduced by 30 % when cattle were housed in straw-bedded deep litter housing, relative to free stalls with concrete floors. This suggests that the physical structure of the bedding material may influence the extent to which manure drains through the bedding and the aerobic capacity of the physical material that allows the

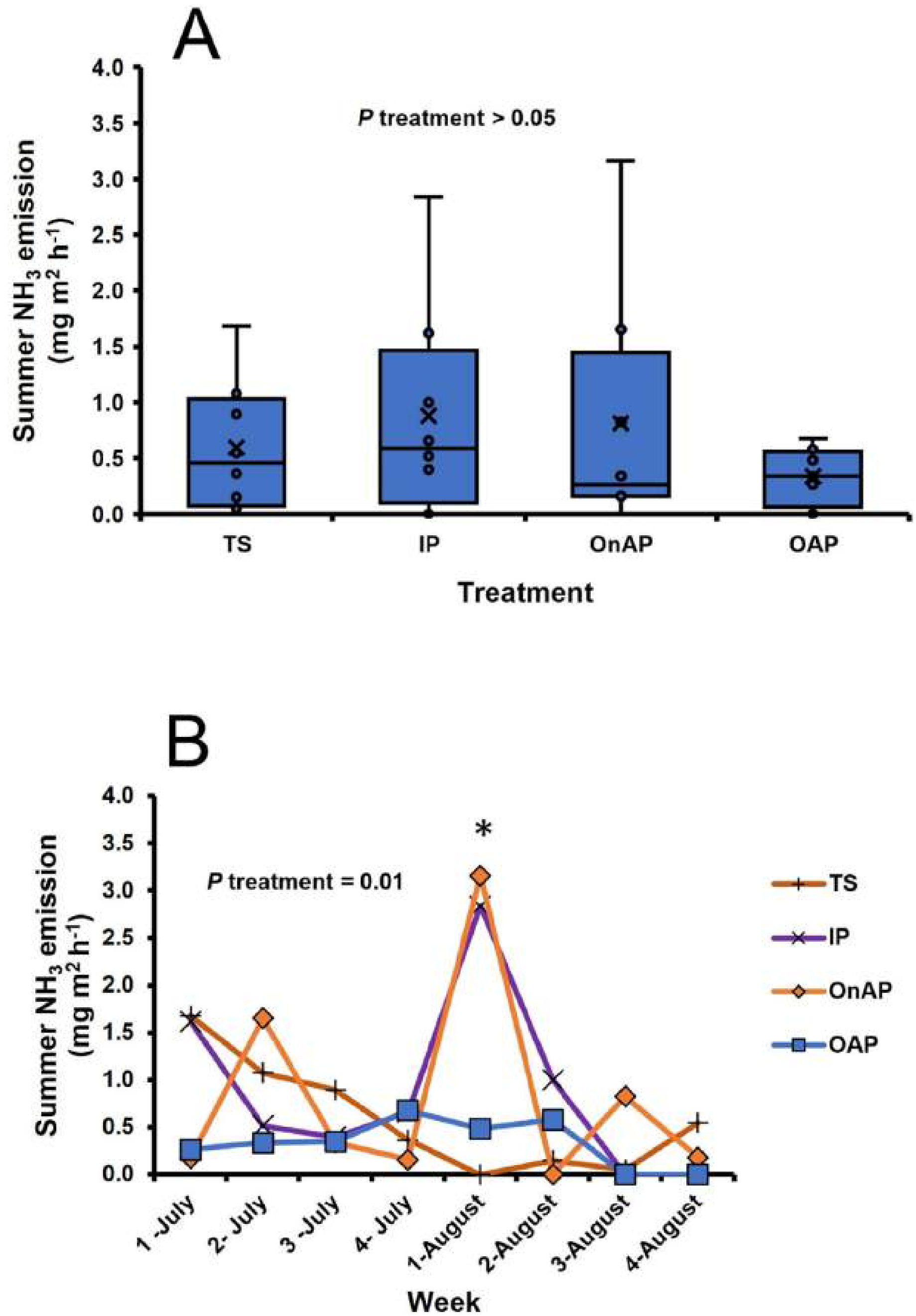
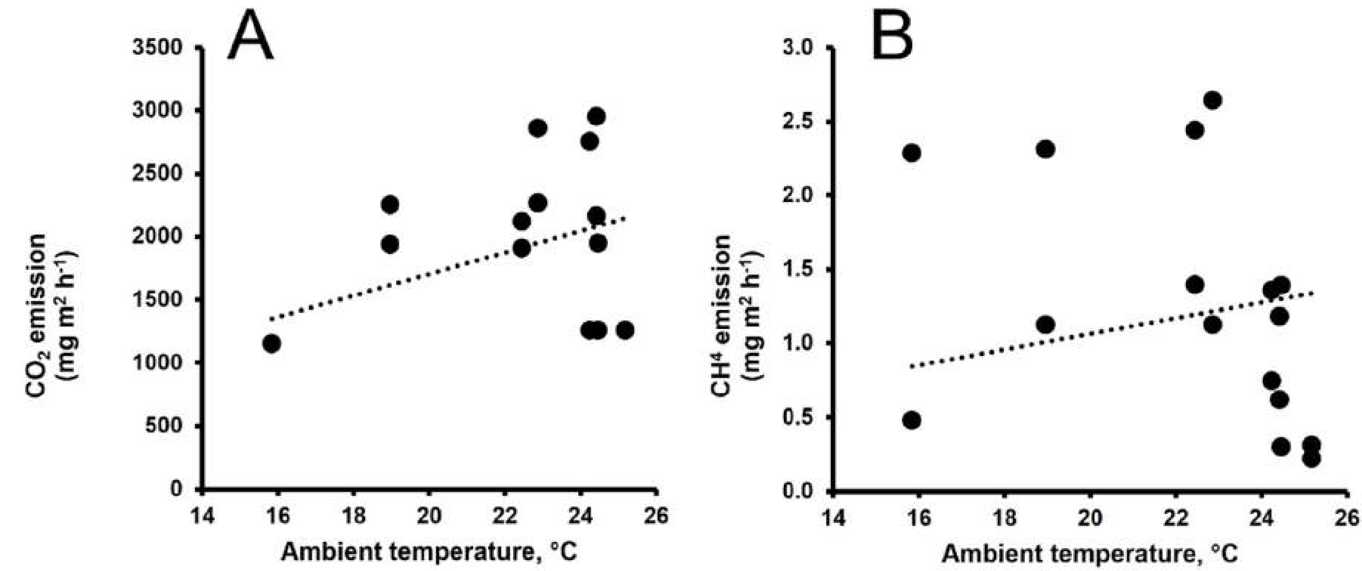


Fig. 11. Effect of indoor tie-stalls (TSs), an indoor pen (IP) and an outside exercise pen, either nonaerated (OnAP) or aerated (OAP), during the summer conditions on overall (A) and time course (B) NH_3 emissions. *Statistically different ($P < 0.05$). Weeks on the X-axis for B indicate the number of experimental weeks in each month.

diffusion of the emission (Misselbrook & Powell, 2005).

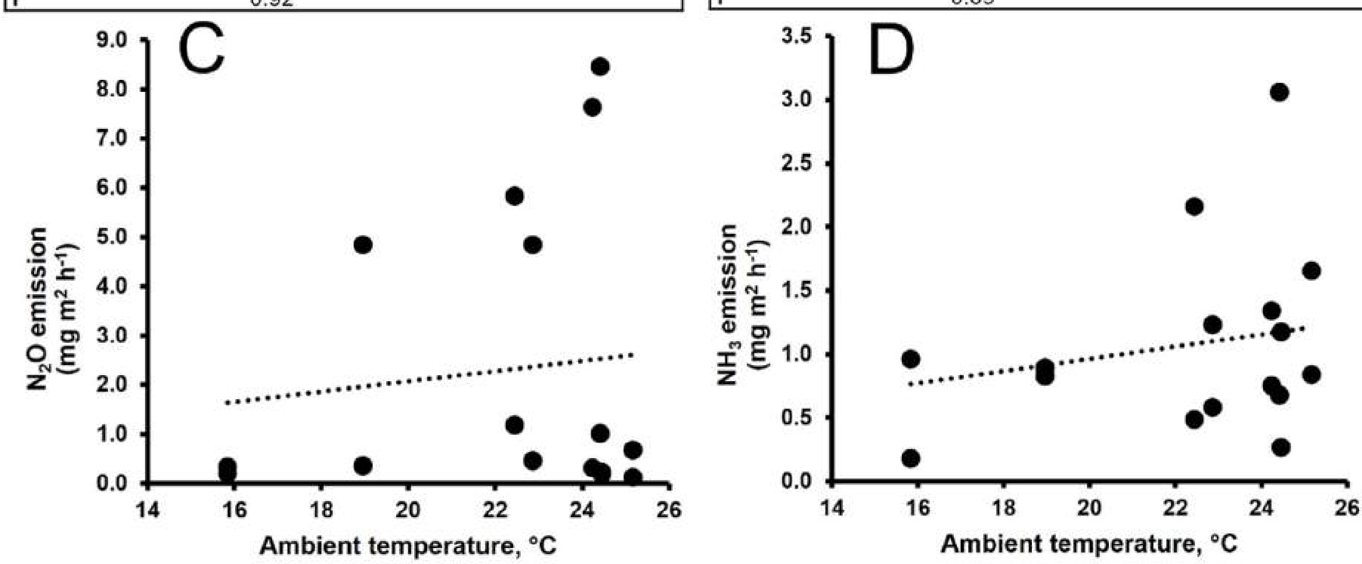
Nevertheless, the results of CH_4 and CO_2 emissions did not reveal the association between these two gases in both indoor and outdoor measurements. This is in contrast with the results of previous studies that showed a linear correlation between CH_4 and CO_2 concentrations (Bjerg et al., 2011; Madsen et al., 2010; Ngwabie et al., 2009; Wu et al., 2012). In addition, studies have reported a ratio between CH_4 and CO_2 concentrations of approximately 0.004–0.08 (Ngwabie et al., 2009; Wu et al., 2012), which is commonly used to predict the emission rate of CH_4 based on the CO_2 concentration (Madsen et al., 2010). These differences between the current study and the previously published studies may be related to the different measurement setups used. Cited studies usually use 2-m-long tetrafluoroethylene–hexafluoropropylene tubes across the building, with uniformly distributed sampling openings, to ensure the same airflow rate across the building (Demmers et al., 2001; Wu et al., 2012). However, in the current study, punctual air mass measurements were used to quantify treatment effects related to individual animal housing, as such models differed in terms of planned objectives. Despite these setup differences, we were able to detect the treatment effects. Thus, the emissions results presented in the current study need to be interpreted with caution because the current emissions do not represent the entire system and do not characterise the total emissions from the systems evaluated here, TS, IP, OnAP and OAP.

The present study showed that outdoor treatments presented higher N_2O emissions, which were higher in the OnAP than both indoor housing systems. Usually, N_2O is a by-product of the microbial processes



Parameter	Estimate	SEM	*P*-value
Intercept	1589	613	< 0.001
Slope	85.17	1.23	< 0.001
R^2	0.90		
r	0.92		

Parameter	Estimate	SEM	*P*-value
Intercept	3.28	0.77	0.010
Slope	0.05	0.002	0.010
R^2	0.66		
r	0.69		



Parameter	Estimate	SEM	*P*-value
Intercept	-0.99	0.23	0.010
Slope	0.10	0.08	0.010
R^2	0.40		
r	0.48		

Parameter	Estimate	SEM	*P*-value
Intercept	-0.51	0.21	0.030
Slope	0.05	0.01	0.030
R^2	0.72		
r	0.75		

Fig. 12. Regression analysis of ambient temperature during summer with recorded emissions of CO_2 (A), CH_4 (B), N_2O (C) and NH_3 (D) under both outdoor conditions (OnAP and OAP).

of nitrification and denitrification, which can be produced and emitted during the aerated composting of organic waste (He et al., 2001). The process of nitrification normally occurs in aerobic conditions, such as under aerated conditions or a continuously turned composting process, where NH_3 is oxidized to nitrate by autotrophic bacteria (Alexander, 1977). Nitrification was not observed in the current study, as N_2O was higher in the nonaerated bedding (OnAP). This suggests that the denitrification process occurs in the anaerobic condition favoured by OnAP, which might simulate the process of a pile of compost, involving the reduction of nitrate to dinitrogen gas primarily by heterotrophic bacteria (Kebreab et al., 2006). Nevertheless, the humidification process by rain and drying sun on these outdoor pads could generate the decomposition of the organic matter (Balcells et al., 2020; Fillingham et al., 2017), an effect that could be stimulated by the high ambient temperature (>25 °C) during summer. In addition, the accumulation of manure in long-period cleaning pens has been associated with increased NH_3 emissions (Monteny et al., 2006; Yang et al., 2016). However, manure accumulation occurred in both outdoor exercise areas relative to both indoor treatments, which are usually cleaned frequently over the day. We should have observed higher NH_3 emissions in both outdoor exercise areas than in both IP and TSs. However, we did not observe this effect on NH_3 emissions. Composting increases the pH and the temperature of the materials, which shifts the equilibrium of NH_4–N and NH_3 towards gaseous NH_3 and is usually released into the atmosphere (Li et al., 2008, 2013; Tiquia, 2002; Wang & Zeng, 2018). Conversely, NH_3 emission rates are commonly highly dependent on floor conditions, manure management (Bougouin et al., 2016; Montes et al., 2013) and ambient temperature (Poteko et al., 2019; Rong et al., 2014). Unfortunately, we were unable to measure GHGs during winter in the present study, which could show the effect of seasonal temperature on GHG emissions. In a laboratory-scale experiment, Misselbrook and Powell (2005) reported the lowest NH_3 emission rate from excreta in the bedding of sand (5300 mg NH_3–N m^2 h^{-1}) and pine shavings (7800 mg NH_3–N m^2 h^{-1}) throughout 48 h, relative to recycled manure (12,100 mg NH_3–N m^2 h^{-1}), chopped corn stalks (12,700 mg NH_3–N m^2 h^{-1}) and straw (10, 200 mg NH_3–N m^2 h^{-1}), suggesting that the physical structure of the bedding and the relative absorbance material capability were the more important factors influencing NH_3 emissions. This difference across bedding materials was only observed numerically in the present study, as many factors could influence this response. The NH_3 emission levels documented in the present investigation during the summer season were substantially lower compared to the emission rates delineated in the laboratory-scale study conducted by Misselbrook and Powell (2005). This disparity may be attributed to variations in experimental conditions, specifically the distinction between laboratory methodologies and the on-farm scenario. Furthermore, the compaction induced by the cows in both exercise areas' bedding (OnAP and OAP) could have influenced emissions by diminishing porosity and impeding aeration within the filter material.

Generally, aeration in the outdoor exercise area of the current study did not lower CO_2, CH_4 and NH_3 emissions, but it reduced N_2O emissions. Garzón-Zuñiga et al. (2007) reported a higher N_2 flux when the aeration rate was increased from 3.4 to 34 m^3 m^{-2} h^{-1}. Although the authors did not measure N_2O emissions, it may suggest higher N_2O emissions due to the positive association between N_2 and N_2O. However, it may be logical to assume that the higher the aeration flux in the later study, the more N_2 will be released into the atmosphere and the higher the nitrogen oxide mass transformed into N_2. This is in contrast with the current study because we observed a reduction in N_2O by aeration in the outdoor exercise area. However, the emission levels were as low as both indoor treatments (IP and TSs). Other authors (Husted, 1994; Kaharabata et al., 1998) have described manure emissions as an intermittent process (in terms of spatial and temporal). This means that emissions levels may depend on stimulation factors, such as solubility (CH_4 will be released from the slurry when CH_4 concentration exceeds the maximum solubility). Methane can also be released spasmodically, either because of a perturbation (feeding, rain, wind) or because the bubbles reach a large size, which leads to episodic CH_4 emissions to the atmosphere. In the specific case of this study, accumulation of manure leads to a composting-like process (air flowing on top and in the drainage; the system may be circulating within the gravel layer and higher), which stimulates CO_2 and N_2O with a lower CH_4 emission in both outdoor exercise areas (OnAP and OAP).

5. Conclusions

The current study aimed to evaluate the effect of exercise areas on dairy cows' effluent properties, and emissions of NH_3, carbon dioxide and GHG during the winter and/or summer conditions. The results of the current study revealed that the effluent composition varied with time, and still, the overall effluent composition, such as BOD and SS, are over environmental regulation limits, especially during winter. Thus, there is still work to improve the concept of exercise pen for dairy cows with a filtering bedding, to decrease construction costs by avoiding drains and geomembranes. It will be of interest in further research to test new filtering materials and bedding depth that can remove more hazardous compounds in the leachates and look for practices that can reduce the collected effluent quantity (e.g. roof). Air injection in the pad did not improve the water quality. Therefore, improvements in the bedding should be made to increase contaminants retention and increasing airflow to facilitate the oxidation process. Conversely, the provision of outdoor exercise to dairy cows involves increased available pen cow surface, which increases the environmental footprint in terms of CO_2 and N_2O but reduces CH_4 emissions. However, the results of the present study need to be interpreted with caution because they do not represent a complete housing system evaluation. Therefore, more experiments are needed to replicate the current setup in different farm scenarios to determine the variability of the tested variables. It is crucial to test new materials that can be used for bedding, aiming to reduce the environmental impact of exercise areas throughout the year.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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