Accuracy assessment of methane emissions measurement systems tailored to mechanically ventilated livestock buildings

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Deux approches différentes ont été utilisées pour quantifier les débits d’air dans les étables des fermes A et B. Courbes de performance des ventilateurs développées à la ferme A et conception d’anémomètres dans notre laboratoire et déployées à la ferme B. La précision des systèmes de mesures a été validée en relâchant dans les bâtiments des masses connues de méthane et quantifiées par le système. La moyenne du ratio de la masse de méthane mesurée par les systèmes et les masses connues relâchées dans les bâtiments A et B étaient de 99,4 et 101,4% pour les deux systèmes avec des écart-types de 16 et 9% respectivement.

Les deux étables ont fait l’objet de mesures des émissions de méthane de leur troupeau respectif entre l’automne 2004 et l’hiver 2007. Les deux productions ont des émissions moyennes de méthane équivalentes à 24,5 et 24,7 L de CH₄ par kg de lait produit. La production moyenne de méthane émis par les troupeaux rapportée sur la base de matière grasse (MG) produite par chacune des productions est de 612 L CH₄ par kg de MG pour la ferme A et de 688 L CH₄ par kg de MG pour la ferme B.

Mots-clés : Méthane, bovin laitier, instrumentation, gaz à effet de serre.

INTRODUCTION

In 2010, the Canadian agricultural sector produced 56 Mt CO₂ eq. (Environnement Canada 2010), which accounted for 8.1% of national GHG emissions and represents an increase of 9 Mt over the 1990 level. Ruminant enteric fermentation, mainly in cattle (dairy and beef) operations, contributes one-third of GHG emissions from the agricultural sector. From 1990 to 2008, GHG emissions from enteric fermentation in livestock increased by 29%. During the same period, the feeder cattle livestock population increased by 29%, whereas the dairy industry decreased its livestock population by 28% as a result of significantly improved dairy cow productivity. GHG Emissions from that industry decreased by 15% during that period (Statistique Canada 2006). Cattle and dairy operations contribute to greenhouse gas (GHG) emissions and, in 2008, were responsible for emissions of 4.6 Mt CO₂ equivalent (CO₂ eq) (Environment Canada 2010). Canada uses the Intergovernmental Panel on Climate Change emission factors to establish its inventory of GHG produced by cattle. However, a cow’s methane emissions vary depending on the animal’s diet composition, age, weight, and environment (Wilkerson et al.1995; Sutton et al. 1986; Shabi et al. 1999; Dohme et al. 2000; Harper et al. 1999). Few studies in Canada have drawn a connection...
between the production levels of dairy herds and their GHG emission levels (Boadi et al. 2004). The need to accurately estimate the impact of current and new livestock management practices on the mitigation level of enteric methane emissions has driven the development of tools capable of quantifying herd emissions on commercial dairy farms.

Around the world, various methodologies have been used to quantify GHG emissions. The infrared laser measurement of methane emissions is an approach that is particularly applicable to livestock in feedlots or on pasture (Desjardins et al. 2004). However, that technique requires continuous wind from a direction that remains constant over time. Because of climatic variations, farm structures and landscape interferences the infrared quantification method is not accurate and has difficulty in quantifying emissions continuously on a daily basis. The tracer gas technique can also be considered. It applies to both livestock on pasture and livestock in buildings, but the accuracy was limited by the tracer release rate uncertainty and the difficulty to have a uniform tracer concentration distribution. This kind of method can introduce an overall error of 30% (Kaharabata et al. 2000).

The main objective of this study was to design and develop reliable, robust, and accurate tools for measuring the methane emissions produced by commercial dairy herds without interfering with standard producer practices or affecting herd performance.

**METHODOLOGY**

**Mass balance over the buildings**

The mass balance is based on the hypothesis that when a building is under negative pressure, the flow rate of air into the building is equal to the sum of the flow rates of the air that is exhausted by the fans. Each fan was instrumented and calibrated to obtain an effective flow rate curve under actual conditions of use. Air samples were taken continuously near the air inlets and outlets and sent to an analyzer for determination of their methane concentration. The difference between the methane mass coming out of the building and the methane mass entering the building is attributable to methane production by the herd. The mass balance that was used is expressed in Eq. 1,

\[
\dot{m}_{CH_4} = \sum_i (Q_i \cdot [CH_4_i]) - \frac{T_i}{T_o} \sum_i Q_i \times \frac{\sum_j [CH_4_j]}{m}
\]

where:

- \(\dot{m}_{CH_4}\) = mass flow rate of the methane produced by the herd,
- \(Q_i\) = air flow rate at fan \(i\) (m\(^3\) h\(^{-1}\)),
- \([CH_4_i]\) = methane concentration at fan \(i\) (g m\(^{-3}\)),
- \([CH_4_j]\) = methane concentration at the building air inlet sampling point \(j\) (g m\(^{-3}\)),
- \(n\) = number of fans sampled,
- \(m\) = number of air inlet sampling points, and
- \(T_i/T_o\) = the temperature compensation factor for air density at the inlet.

**Instrumentation of the buildings**

The accuracy of the mass balance depends on the accuracy of the measurements of methane concentration in the air samples and of the flow rates at the various fans. Special attention was paid to the accuracy of flow rate measurements, with the result that two distinct designs were developed.

![Fig. 1 Floor plans of selected barns (Farm A and Farm B)](image-url)
The selected barns needed to be mechanically ventilated to maintain negative static pressure inside the building at all times so that the methane produced by the herd was exhausted by the fans rather than through openings in the building envelope. The level of negative pressure inside the two buildings was verified with a micro-manometer (AirData Multimeter ADM-850, Shortridge Instruments Inc., AZ, USA) under the minimal mechanical ventilation conditions that prevail in the winter during the coldest periods.

Figure 1 provides the floor plans of selected barns A and B. On farm A, the main section of the livestock building measured 61 m long by 12 m wide and was mechanically ventilated. A naturally ventilated section measuring 23 by 12 m to the north end of the main building was the main fresh air inlets of the barn. The livestock area measured 1020 m² and contained 110 tie-stalls and six 13-m² pens. In summer, mechanical ventilation was provided by four fans measuring 1.22 m in diameter (model 3105400, Ventec, St-Hyacinthe, QC, Canada) that were located at the south end of the barn and created tunnel ventilation. In winter, four fans measuring 0.51 m in diameter (model EF 4116000, Ventec) that were located on the west wall of the barn were used. A fifth 0.51-m fan operated at all times to ventilate the manure transfer room at the southwest end of the barn.

The barn on the second farm (Farm B) measured 53 by 10 m, for an area of 530 m². The barn contained 72 tie stalls, one 23-m² pen for calving, and one 50-m² pen divided into five sections for calves and heifers. For summer ventilation, the building was equipped with three fans measuring 0.91 m in diameter (Vic Classique 36 in., Vic Ventilation, St-Hubert, QC, Canada) that were located at the west end. In winter, five fans measuring 0.40 m in diameter (Vic Classique 16 in., Vic Ventilation) located on the north wall were used.

A schematic diagram of the data acquisition systems for farms A and B is provided in Figure 2. The system was made up of a central data acquisition system connected to 10 secondary sampling stations located near the eight fans and the two air inlets for natural ventilation. Four extra air-sampling points were located between the new and the old section of the barn. The central data acquisition system used remote data and control modules (FieldPoint, National Instruments, Austin, TX, USA) linked to a remote computer. A system consisting of 14 solenoid valves mounted on a manifold (Bürkert 6011, Bürkert Corp., Germany) was used to successively select, one at a time, the sampling lines that connected the central system to the secondary stations and carried the air to be analyzed. A vacuum pump (Seco SV1003, Busch, Germany) aspirated the sample to be analyzed. A 50-µm vacuum filter (IDN-6G inline filter, Parker, USA) was placed upstream of the pump (FestoVAF-PK-6, Hauppauge, NY, USA) to prevent dust from damaging the equipment. The sample passed through a second filter (1-µm Teflon) and a thermoelectric chiller (model 624, Universal Analyzers Inc., Carson City, NV, USA) to prevent dust from accumulating in the analyzer’s optical chamber and to lower the dew point of the sample to about 8°C in order to minimize the interference of humidity and prevent water condensation in the optical chamber. Because the solubility of methane in water is very low, the methane into the condensate was negligible. It was equal to approximately of 0.01 ppm g/g. A needle valve (H-300 Series, Ham-Let, USA) was used to maintain the flow rate of the air sample to the analyzer at 30 L/h. Excess air sample was exhausted to the atmosphere, and an overpressure relief valve (type BLC check valve, O’Keefe Controls, Trumbull, CT, USA) eliminated the risk that the sample would be contaminated by ambient air if for any reason the sample flow rate was not sufficient. The system
used an infrared methane analyzer (MGA3000, ADC Gas Analysis, UK) with a range of 0 to 1000 ppm and accuracy of 1.0% of full scale. The sampling stations contained a type T thermocouple transmitter that had a signal of 0 to 20 mA (model TT205, Minco, Minneapolis, MN, USA) and to which a type T thermocouple located near the air inlet or outlet was connected. A 0-to-1-in. H₂O pressure transmitter (Modus T40, General Electric, USA) read the pressure differential between both sides of the fans or the wall with natural ventilation. A proximity sensor (SRF-3A, Micro Switch, Honeywell, USA) was used to determine the fan rotation speed. Food-grade clear polyvinyl tubing was used to transport the air samples.

Information on the prevailing weather conditions (barometric pressure, temperature and air humidity) was provided by a weather station (Weather Monitor II, Davis Instruments, Hayward, CA, USA). An anemometer and a wind vane installed on the barn roof were connected to the weather station. A humidity transmitter (model HX92AC, Omega Engineering, USA) was placed in the centre of the barn to detect humidity condition that could affect the herd.

Cylinders of pure grade 5 nitrogen and 1000-ppm methane balance nitrogen (Praxair, Canada) were used to validate the accuracy of the analyzer. The analyser manufacturer recommended to correct the offset drift once per day and to correct the span drift once per week. Because our analyzers did not compensate for temperature the offset correction was carried out every hour.

The data acquisition and control system, the scale, weather station, and methane analyzer were all connected to the same computer. An application developed in the LabVIEW environment (National Instruments) integrated all components of the system and coordinated the taking of various readings on a regular and continuous basis. One “monitoring cycle” was the time required by the system to analyze methane concentration of all air samples collected at the inlets and at the fans in operation. Monitoring cycles varied from 6 to 30 min depending on the numbers of fans in operation.

The measurement system on Farm B differed from the one on Farm A. The vacuum pump used on Farm A to aspirate the air samples, was replaced by a GAST 3032-101A pump (Gast Corp., USA) on Farm B. The weather station that is normally placed outside the building was installed inside building B. Two temperature sensors provided air temperature readings at either end, near the air outlets. A mean air temperature in the barn was calculated from the two readings provided by the weather station. In addition, having the weather station inside the building ensured that the air humidity inside the barn was measured without the need for another sensor, unlike the set-up on Farm A. Specific anemometers for each fan were built and mounted on fan hoods at farm B. With this approach, it was not necessary to modify the barn’s fans in order to install instruments for measuring rotation speed, temperature, and static pressure across each fan, unlike the set-up on Farm A.

**Determination of the air flow rate in the buildings**

A calibration chamber (Fig. 3) that met the ANSI/AMCA standard (ANSI/AMCA 210-99 ANSI/ASHRAE 51-1999 2000) was built and instrumented so that a custom air flow rate measuring instrument could be developed. Air was forced into the chamber by a variable-speed fan (Double-Width AcoustaFoil Fan 201, New York Blower Company, Willowbrook, IL, USA). The air passed through a conduit that measured 0.46 m in diameter equipped with an air straightener. A series of Pitot tubes measured the airflow velocity in the conduct. The air was discharged into a...
The anemometers developed were thereafter used on Farm A to calibrate and establish the fan performance. They were temporarily mounted upstream of each fan during the calibration. An in situ calibration curve to establish for each fan the flow rate as a function of various static pressures through the building envelope and fan RPM was established directly on Farm A for each fan. In operation, the system makes used of the static pressure near each fan and their specific calibration curve to estimate their flow rates.

The anemometer approach was used on Farm B as well. They were inserted into vent hoods for the five 0.30-m and the 0.40-m fans on the farm. The instrumented hoods were calibrated in our laboratory according to the standard ANSI/ASHRAE 51-1999 and thereafter permanently installed on Farm B. Three anemometers made up of 0.86-m impellers were also built and installed directly at the outlet of the 0.91-m fans. All eight anemometers had been calibrated in the laboratory. Proximity sensors (model E2E-X10E1, Omron Corporation) were used to determine a wave train whose period was a function of the rotation speed of the impeller.

**Determination of the accuracy of the measurement systems on Farms A and B**

In the systems that were developed, the entire building made up the measuring instrument. Each component of a measuring instrument, whether laboratory- or building-scale has its own intrinsic error. However, the error of an instrument is not determined by adding up the intrinsic errors of its components, but rather by assessing the instrument against a known standard. For example, although a digital scale has errors associated with the mechanical parts of the platform, the load cell, and the analogue-to-digital converter, the error of the scale is determined by comparing the readings obtained with standards of known mass. That exact approach was used for the Farm A and B systems with the release of known masses of methane into the buildings. The monitoring equipment quantified the mass of methane released as well as the mass of methane produced by the dairy herd. The herd emission over the release period was estimated from the mean methane flow rate before and after the release period. The herd emission was subtracted from the mass of methane measured by the monitoring system. The ratio of the mass of methane measured over the known mass of methane released was used to establish the accuracy of monitoring equipment on both farms. The release system consisted of a scale (model GSE465, GSE Scale Systems, Novi, MI, USA) with a capacity of 75 000 ± 1 g on which a cylinder of pure grade 2 methane (Praxair Canada) was placed. A solenoid valve (ASCO, Florham Park, NJ, USA) was operated to release the gas. A flowmeter (Dwyer, Michigan City, IN, USA) was used to adjust the methane flow rate to a level equivalent to one to three times the background flow rate of the methane emitted by the herd (2.5-7.5 m³ h⁻¹ farm A and 1.5-4.5 m³ h⁻¹ farm B). The flow rate of the release was constant over a period varying...
from 20 min to 3 h depending on the ventilation conditions in the building. The calibration period included at least 3 air exchanges into the barn during the release period and an additional 3 air exchanges after the release period to ensure that all the methane released has been quantified by the systems. The mass of the gas cylinder was recorded during the release period. The methane was released about 60 m away from the summer fans through a perforated polyvinyl transverse duct on Farm A and along the longitudinal axis on Farm B. The non-point source release inside the barn is more representative of herd emissions.

Figure 6 illustrates the method used to break down the mass flow rate of methane measured by the system during the calibration test. The calibration period was defined as beginning with the first reading after methane release began ($t_i$). The calibration period included all readings during the release as well as a post-release period that was equivalent to the time required for approximately four air changes in the barn. The calibration period was considered finished when the residual methane had been entirely exhausted, at time $t_f$. The system readings after $t_f$ once again represent the emissions from the herd. The total non steady state methane recovery over the period $t_i$ and $t_f$ was determined by numerical integration by trapezoid method. The contribution of the herd to the mass of methane recovered during the calibration period has been estimated, a straight line was drawn between the mean of the two readings preceding the release ($t_i$ and $t_{i-1}$) and the mean of the two readings following the release ($t_f$ and $t_{f+1}$). Based on the historic of measurements in similar conditions (ventilation, climatic conditions, times period) it was observed that the variation in the emissions from the herd was negligible over short periods. Tremblay and Massé (2008) demonstrated previously that the methane emissions from a herd of lactating cows could vary from 12 g/h to nearly 22 g/h per animal over a 24 h period, with large increases in methane emissions following meals. The periods with a lower amount of activity in the barn, such as in the afternoon or at night, are favourable times for methane release; during such periods, variations in the herd’s methane emission rates are relatively small, and the use of a straight line to estimate the methane emissions attributable to the herd is more appropriate. Those periods were targeted for performing calibration in the buildings.

The calibrations with important variations in the ventilation rate in the building caused by the starting or stopping of fans were discarded. Because the sample concentration was analyzed on a grab basis within a cycle, and because that concentration is multiplied by the mean flow rate at the fan during the cycle period, the starting or stopping of fans during the calibration test would affect measurements accuracy of the mass of methane exhausted by the fan. Given that the number of cycles during a calibration test was relatively small (3 to 10 measurement cycles per test), these variations in fan flow rate would result in overly large fluctuations.

Attention was paid to ensure that a negative pressure (min 5 Pa) inside the building was maintained during the calibration, so that the entire mass of released methane would be exhausted by the building’s mechanical ventilation and captured by the instruments. The static pressure was measured by pressure sensors (Modus T30, General Electric) near the building’s air inlets, across the walls. Due to some climatic conditions, calibration test were not considered when the negative pressure was below 5 Pa.

Fig. 7. Summary of the results, for the calibration tests conducted on Farm A, grouped by ventilation type.
Methane release tests to establish the accuracy of the systems were carried out in each building at different times over the measurement period. On Farm A, 20 release tests were conducted between October 13, 2005, and September 16, 2006. On Farm B, nine release tests were conducted between December 14, 2005, and March 17, 2006. On Farm B, only the winter period was studied, because the animals were on pasture during the summer.

Methane emissions from the herds
The methane measurement system was in operation more than 90% of the time over the period under study. When the static pressure inside the barn was positive, methane was exhausted via both the air inlets and other openings in the building envelope. The data were excluded when the static pressure was positive or slightly negative (less than 5 Pa). On Farm A, a section of the building was naturally ventilated over the summer. During the spring (April, May, and June) and fall (October, November) only one 48 inches fans was in operation to maintain minimal ventilation rate. But under this condition, the ventilation rate was not sufficient to create a negative pressure of 5 Pa in the building when the natural ventilation curtains were lowered. This resulted in imprecise mass balances that were also excluded.

Herd composition
Weekly surveys were carried out to determine the herd composition by animal categories. The herd on Farm A barn varied between 90 and 128 cows during the period under study. About 37% of the animals in the building were replacement animals (calves, heifers of various ages, and dry cows). During the summer, the dry cows and heifers, accounting for between 5 and 20% of the herd, were generally outside on pasture. Farm A herd was composed at 85% Holstein and 15% of Canadienne. Farm B housed between 67 and 72 animals during the study, of which about 45% were replacement animals. All the cattle were Holstein.

Diet feed samples were taken each week and analyzed by the Agri-Analyse laboratory (Sherbrooke, QC, Canada). Certain feed components were analyzed with wet chemistry, particularly the Shur-Gain concentrate and the ground corn from Farm B. Infrared analysis was used for the other feed components.
On Farm A, the herd was fed a typical total mixed ration (TMR). For dairy cows, the TMR consisted of 42% alfalfa silage, 25% corn silage, 6% dry hay, and 27% concentrates. The rations fed to dry cows and heifers of all ages were equally typical of diets for those animal categories, because the rations contained little energy or protein concentrates.

On Farm B, timothy hay in round bales was continuously available to the herd and supplemented with ground corn and Shur-Gain commercial concentrate. The producer provided each lactating cow with an average of 7 kg grinded corn and 2.5 kg of concentrate.

Analysis of the chemical composition of the rations shows that the TMR fed to the lactating cows on Farm A had mean crude protein, neutral detergent fibre, acid detergent fibre, and fat contents of 13%, 51%, 31%, and 1.8%, respectively. The hay fed on Farm B was of medium quality, with protein, acid detergent fibre, and neutral detergent fibre contents of 11.3%, 39.7%, and 69%, respectively. The compositions of the Shur-Gain concentrate and grinded corn were typical of those types of ingredients, which are often used in dairy cow diets.

**Milk production and composition**

Milk production and composition data were obtained monthly from Valacta (Saint-Anne-de-Bellevue, QC, Canada) for each farm. However, the contract between farm B and Valacta was for only 10 months per year. No analyses were available for the months of July and December.

The mean milk production of the Farm A herd was recorded at 1338 kg/d, which corresponded to a mean yield of 21 kg/d per cow. The mean milk production of the Farm B herd was recorded at 910 kg/d, which corresponded to a mean yield of 25.7 kg/d per cow. The milk from Farm A had mean fat and protein contents of 3.92% and 3.14%, respectively, in comparison with 3.64% fat and 3.27% protein at Farm B.

**Comparison of means**

In order to discuss the similarity or difference between two series of calibrations, the test of equal variance of the series was used. Variances were compared with samples corresponding to t-student samples with an equivalent degree of freedom. Statistical complementary tools analysis from MS Excel were used for these analyzes. A probability criterion of 0.05 was used.

**RESULTS AND DISCUSSION**

**Calibration tests**

The 20 tests on Farm A averaged 99.4% for recovery of the released methane, with a standard deviation of 16%. However, a significant difference was observed between the tests conducted under winter ventilation and those conducted under summer ventilation ($P < 0.0028$), with means of 89.3% in the winter and 109.5% in the summer (Fig. 7). That difference is explained by a number of factors. The anemometers used to determine the airflow rate curves for the 0.51-m fans, which operated in the winter, were different from the anemometers used for the 1.22-m fans, which operated in the summer, each anemometer has a specific precision. The position of our static pressure tubes could affect the anemometer precision. The fan calibration methods could also affect the accuracy of our calibration tests. Under summer ventilation, the ventilation rate on Farm A was equivalent to 25 air changes per hour. The system analysis cycle required 6 min to take all the measurements. The period studied for a 20-min release test required about 30 min: 20 min for the release plus 10 min for the “post-release” period equivalent to four air exchanges. A calibration test under summer ventilation was described by only five system readings. Under winter ventilation, the “post-release” period, equivalent to four air changes, was up to 80 min long for a 20-min release. The period studied for a 20-min release in the winter was described by a minimum of 13 system readings.

The building summer ventilation rate was about 4.5 times higher than the winter ventilation rate (83 000 m$^3$ h$^{-1}$ in summer versus 18 500 m$^3$ h$^{-1}$ in winter). In order to get a representative ambient methane concentration the flow rate of the released methane during the summer was 2 to 2.5 times higher than the flow rate released during the winter calibrations. Nevertheless, the methane concentration measured in the building was in the order of 100 ppmv in the summer versus 200 ppmv in the winter, and the relative error of the methane analyzer accuracy ($±10$ ppm) was more important in the summer than in the winter.

The calibration results show that the accuracy of a measurement system is directly related to the method used for quantifying the building ventilation flow rate. The calibration tests on Farm B indicated that methane quantification systems recovered on average 101.4% of the methane released with a standard deviation of 8.8% (Fig. 8). The tests were all conducted under winter ventilation, because the animals were on pasture during the summer season. The calibration tests on Farm A indicated that methane quantification systems recovered on average 99.4% of the methane released with a standard deviation of 16% (Fig. 7).

The technique used on Farm B to measure the ventilation flow rate which made use of anemometers developed for each fan was more precise than the technique used on farm A. That method required more calibration work in the laboratory but resulted in better reading stability over time. The anemometer method used on farm B required fewer instruments to estimate the building ventilation flow rate. It was also more robust and better adapted to the farm environment. The presence of dust tends to interfere with the static pressure sensors used on farm A. The use of fewer instruments reduces the risk of equipment failure during the experiment as well as the cost of instrumentation.

In comparison with the building on Farm A, the barn on Farm B had the advantage of being much more airtight. The negative static pressure in the Farm B building varied from 30 Pa under winter ventilation to more than 100 Pa under summer ventilation. The Farm A building negative static pressure ranged between 5 and 15 Pa under winter and...
summer ventilation conditions. The low static pressure under the summer ventilation conditions was due to the naturally ventilated section where the curtains were completely open during the summer.

**Profiles of daily methane emissions from the herds on farms A and B**

Figure 9 illustrates the mean daily methane emissions profiles measured on both farms during the month of September 2006. The data are expressed on the basis of milk production on each farm. Farm A housed an average of 57 lactating cows during that period, whereas Farm B housed 35. Milk production reported during September 2006 was $3.32 \times 10^3$ kg for Farm A and $2.30 \times 10^3$ kg for Farm B. The mean hourly methane emission ranged from 16 to 24 g methane per kilogram of milk for both farms, which corresponded to a variation of 50% in hourly methane emission. The two herds did not reach their respective maximums and minimums at the same time of the day. The daily profile is modulated by producer practices. For example, the response of herd emissions following a meal served by a robot that took more than 2 h to feed the entire herd (as on Farm A) lasts longer than the response following a meal served by the producer in a few minutes (as on Farm B). These profiles illustrate the importance of continuous monitoring to capture the hourly methane emission rates variation in order to establish accurately the daily methane emissions.

Despite the differences in daily methane emission profiles, the daily methane production was similar for both farms, as shown in Table 1. When daily methane emissions are expressed in terms of grams of methane emitted per kilogram of milk produced, the results for the two dairy were roughly the same, averaging $19.8 \pm 2.6$ g methane per kilogram of milk for Farm A and $20.0 \pm 2.4$ g methane per kilogram of milk for Farm B. Those results indicate that despite their differences in terms of herd management, the two farms emitted the same quantity of methane for every kilogram of milk produced. The analysis of the composition (fat and protein content) of the milk produced by each herd revealed a slight difference between the herds. When expressed as a function of the quantity of milk fat and protein, the amount of methane produced were respectively 8% and 2% lower for Farm A. However, the differences were not significant.

<table>
<thead>
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<th>Month</th>
<th>Farm A</th>
<th>Farm B</th>
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<tr>
<td></td>
<td>$g_{CH_4}$ kg$_{milk}^{-1}$</td>
<td>$g_{CH_4}$ kg$_{fat}^{-1}$</td>
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<tr>
<td>Nov 2004</td>
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Table 1. Methane ($CH_4$) emissions relative to milk production for each farm.
CONCLUSION

The two different methane emissions measurement systems used on farms A and B provided similar levels of accuracy. When known quantities of methane were released into the buildings, the recovery rate of the methane released averaged 99.4% on Farm A and 101.4% on Farm B. However, the accuracy of the system on Farm A was different for summer and winter building ventilation. On farm A, the calibration results showed underestimation in the order of 10% under winter ventilation and overestimation of 10% under summer ventilation.

The method used on farm B for quantifying the fan flow rate by means of a specially built anemometer that is inserted into a fan hood similar to ones already in place on the farm and for which a calibration curve has been established has many advantages. The equipment is easy to install and does not require any modifications to the ventilation systems on the farm for establishing reference curves on site or to the farm’s fans for determining their rotation speed. At the end of the project, the equipment is dismantled without any modifications to the barn ventilation equipment. Also significant is the fact that this method involves fewer instruments and is therefore less expensive to implement.

Both measurement systems developed in this project are accurate enough for establishing methane emission factors from dairy herds under business as usual practices and to assess the efficiency of best management practices. These systems do not interfere with the farm operations.

The continuous monitoring of methane production from two commercial dairy herds reveals important hourly fluctuations in methane emissions. The observed fluctuations ranged between 16 g_{CH4} kg_{milk}^{-1} h^{-1} and 24 g_{CH4} kg_{milk}^{-1} h^{-1}. This shows that it is necessary to continuously monitor the methane emission in order to estimate precisely the herd’s daily methane emissions.

On the two farms investigated, the difference in herd management (feed, herd composition, herd productivity, etc.) did not result in significant differences in the amounts of methane emitted relative to milk production, milk fat and protein contents. The measured methane emissions for Farms A and B corresponded to 24.5 and 24.7 L methane per kilograms of milk produced, respectively.

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