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Emissions of carbon dioxide and methane from dairy cattle manure

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Abstract. There is an increasing interest in reducing production and emissions of greenhouse gases to combat global warming. Greenhouse gases can be produced through animal production operations. One of the major sources of greenhouse gases emitted from the animal farming is dairy cattle barns. This study measured the CH₄ and CO₂ emissions from dairy cattle manure decomposition trapped inside the static chambers through anaerobic digestion process by bacteria and at regular intervals by focusing on animal age and manure storage method. Samples were analyzed using gas chromatography for the estimation of CH₄ and CO₂ emissions. Four Friesian cows were used representing two stages of cow age (3 and 10 years old) and 1 kg of fresh manure samples were collected (feces and mixture of feces with urine). It was found that CH₄ and CO₂ emissions produced by cattle at the age of 3 years were higher than age of 10 years. In addition, gases emitted from fresh slurry feces were higher than liquid manure for both ages (3 and 10 years). This is due to the fact that the organic matter degradation in the feces and amount of fresh slurry feces is twice the amount of fresh slurry feces used in the liquid manure, as well as the organic matter in the manure mass for the age of 3 years is higher than for the age of 10 years. The findings from this study can provide information for improving manure management practices in animal farms.

Keywords: Carbon dioxide, Methane, Greenhouse gas, Animal manure, Dairy cattle

Track Name: Advanced Technology and Renewable Energy

1. Introduction

Animal production farms can emit a variety of air pollutants through gas emissions, which are produced by the animal production processes such as enteric fermentation, confinement barns, manure storage, treatment systems, and manure applied to land for crop nutrients [1]. These animal breeding operations cause the greenhouse gases (GHG) to be emitted into the atmosphere and remains in the atmosphere. This in turns absorbs and emits radiation within the thermal infrared range, keeping the planet's surface warm [2-3]. The major greenhouse gases are carbon dioxide (CO₂), water vapor (H₂O), methane (CH₄), nitrous oxide (N₂O), ozone (O₃) and chlorofluorocarbons (CFCs) [4-6]. As a result of these emissions, animal production is considered as one of the most significant causes of air pollution from the agricultural sector [7]. CH₄ and N₂O emissions from enteric fermentation, manure



storage and handling, and crop and pasture land are all significant sources of GHG emissions from dairy farms [8]. Air pollutants emission from these animal production facilities are influenced by many factors including type of animal, farm operation, ventilation and temperature [9]. Animal feeding operations (AFOs), which are large-scale facilities where livestock and poultry are raised for food processing, release various biological and chemical contaminants into the atmosphere [10]. Odors, gases such as hydrogen sulfide (H_2S), ammonia (NH_3), methane (CH_4), particulate matter, and bio aerosols are among the gases and materials emitted [11].

According to one report, agriculture contributes about 18% of the total global anthropogenic emissions of greenhouse gases, including CH_4 and CO_2 emissions with 9% and 34%, respectively [12] [13]. Methane and carbon dioxide are produced from manure through the anaerobic digestion process of an organic matter decomposition process. Anaerobic digestion is a microbial process that results in the decomposition of organic matter in manure in the absence of oxygen, resulting in the emission of greenhouse gases (GHGs) [14]. Such process is done through common interaction of four metabolically-linked microbes that are in hydrolytic, acidogenic, acetogenic and methanogenic stages [15-16]. Dairy cattle manure is one of the major sources of greenhouse gases emitted from dairy farming where it adversely affects the health of human, animal and the environment [17]. These gases have potential effects on changing the global climate and may especially be a concern to animal health in confined buildings [18]. Therefore, novel research to measure emissions from dairy cow manure, are needed to establish a model emission scopes for livestock farms and help in determining the impact. From the environmental and management factors of these emissions, mitigation strategies can be developed. Furthermore, measuring the amount of emitted gases from dairy manure mass is needed to reduce extreme climate change, mitigate pollution and provide a database that can be deemed useful to improve and monitor the emission impacts.

The present study aims to measure the amount of CH_4 and CO_2 emitted from manure of dairy cow barns, with a focus on the animal age and the manure storage method. This helps identify the influence of the animal's age and the manure storage method on the emission of GHG gases from a dairy cow manure. There are several factors affecting the emission on a farm level including feed, cattle, manure management and climate. Therefore, it is important to understand the representative characteristics for many dairy farms and connect the adopted manure management practices to greenhouse gas emissions for setting recommendations and policies to reduce environmental risks [19]. Hence, quantifying GHG emission from all livestock farm sources is needed for those who seeks for a solution in climate change that is related with the livestock sector [20].

1.1. Livestock manure

Dairy cows are a major source of CH_4 and CO_2 emissions, where CH_4 is produced through anaerobic digestion. As the CO_2 is produced, it is then emitted through both aerobic and anaerobic digestion due to the microbial decomposition of organic matter [21]. The decomposition of manure is done through anaerobic process leading to the decompose of organic matter that interacts with four groups of metabolically microbe-related hydrolytic, acidogenic, acetogenic and methanogenic phases leading to the output of methane and other gases [15]. Not only that, livestock manure is also a potential source of pathogens [22]. Animal production processes generate abundant amounts of animal manure, which requires appropriate management. Therefore, there is a need for appropriate disposal and management of manure in order to avoid the adverse environmental and public health affects [23].

1.1.1 Methane emission

Methane (CH_4) is a colorless, scentless and inflammable gas that exists naturally in the atmosphere and lighter than air. With a global warming potential about 25 times more than CO_2 , methane affects the ozone layer degradation [24] and is the main GHG emitted from manure in storage [25]. The emission of CH_4 occurs from ruminant animals by enteric fermentation and anaerobic storage of manures at temperate conditions. In fact, enteric fermentation and manure management is responsible

for 35–40 % of the total anthropogenic CH₄ emissions and 80 % of CH₄ emission from agriculture [26].

1.1.2 Carbon dioxide emission

Carbon dioxide (CO₂) is naturally present in the Earth's atmosphere through carbon cycle. It is one of the main GHGs contributing to the greenhouse effect and its anthropogenic activities may produce about 8 billion tons of CO₂ per year [27]. The major source of CO₂ emitted from solid manure is by the aerobic production of composting process. This process is affected by many factors, such as moisture content, temperature, carbon/nitrogen ratio, carbon compounds degradability, pH level and the physical structure of the organic material. It has been estimated that approximately 12.5 % of the total global GHG emission are from the livestock sector and 80 % of the total emission from agriculture is from the livestock sector [26].

1.2 Mitigation strategies of gases emission

There are many different strategies proved to be a potential in reducing GHGs emission from manure. To mitigate the impact of animal production operations on climate change there are some of the technical options such as carbon sequestration, improving diets to reduce enteric fermentation, improving manure management, and more efficient use of fertilizers [28]. In some areas, unsustainable manure management practices include a variety of disposal methods that are still commonplace with cost being one of the factors [29]. Hence, most practices involve decreasing storage duration, improving timing and application of manure, used of anaerobic digesters, covering the storage, utilization of a solid separator and changing the animal diets [30].

2. Methodology

The methodology of this study includes the measurement of CH₄ and CO₂ emissions emitted from fresh dairy cow manure samples, trapped inside static chambers by using gas chromatography. Collected manure sampling were placed in static chambers and gas emitted by the samples were collected at regular intervals of 48 hours for gas chromatography (GC) analysis. The data were analyzed using one-way ANOVA with SAS System-2009 used to run the linear regression analysis for both CH₄ and CO₂ emissions.

2.1. Samples collection

Manure samples from four Friesian cows were collected from the livestock farm located in Serdang, Selangor, Malaysia (Table 1), represented by two different age stages (3 years and 10 years) to measure gases emission from manure mass. Intact unpregnant cows were selected which were disease-free and feeding on the same diet of 4 kg concentrated feed per cow daily.

Table 1. Specifications of the selected Friesian cows.

| Cow Number | Weight / kg | Age / y |
|------------|-------------|---------|
| T083 | 495 | 10 |
| T092 | 552 | 10 |
| T1404 | 396 | 3 |
| T1405 | 408 | 3 |

Two tests were used to measure the gases quantity (CH_4 and CO_2) emitted from the manure mass. The first test measured gas emitted from fresh feces (fresh slurry feces) and the second test measured gas emitted from a mixture of feces with urine (fresh liquid manure) at equal amounts of 1 kg for each sample. Fresh slurry feces (FSF) and fresh liquid manure (FLM) were collected from each cow and placed in static chambers prepared for this purpose.

2.2. Data collection and instrumentation

The static chambers were transferred to a laboratory for GC analysis of gas samples and were done by collecting from the top of the chamber at regular intervals of 2 days. The static chambers were maintained at a temperature of 20 °C to 25 °C. The gas samples were collected from the top of chamber by a 25 mL syringe which were then injected into 10 mL vials prepared. From the vials, 1 mL of the gas samples were injected into the gas chromatography. Linear regression analyses were analysed using one-way ANOVA with the differences between two age stages groups and correlation between related parameters performed.

3. Results and Discussion

CH_4 and CO_2 emitted from the Friesian cows manure mass were measured based on the two age stages (3 and 10 years) and manure storage method; FSF and FLM. Due to variations in the gas sampling times and the animal age, various concentrations of CH_4 and CO_2 gas emissions were observed.

3.1 Methane emission

The results of this study showed an increasing CH_4 emission gradually from both FSF and FLM manure for both ages. Differences in the recorded concentrations of the CH_4 is shown emitted from the manure mass in the two age stages (3 and 10 years) and in the manure storage method. For the FSF storage method, the minimum and maximum values for CH_4 emissions ratio at all gas samples were between T_0 (0.00 %) to T_4 (31.41 %) for the age of 3 years. This emissions ratio was much lower for the age of 10 years with the minimum and maximum values between T_0 (0.00 %) and T_4 (12.67 %) only. As for the FLM storage method, the minimum and maximum values of CH_4 emissions ratio at all gas samples were between T_0 (0.00 %) to T_4 (10.79 %) for the age of 3 years, while the 10 years of age emission ratio being lower at only T_0 (0.00 %) to T_4 (3.02 %). Figure 1 represents a summary of the methane emission ratio with the highest value was obtained from FSF and 3 years of age and the lowest value was observed from FLM and 10 years of age.

These findings may have been contributed by the microbial community growth, which leads to organic matter decomposition and the hydrolysis process of urea in urine gradually increasing methane emission over time. The amount of CH_4 released by manure management operations is determined by three main factors which are the manure management system, the surrounding environment, and the amount and composition of manure [31]. It is also observed that CH_4 emissions from only fresh slurry feces for both ages are higher compared to the liquid manure mixture. The higher organic matter presence in the fresh slurry feces justified the finding as 1 kg of FSF was used compared to the FLM with only 0.5 kg of fresh slurry feces used and diluted with 0.5 kg of urine. These results correspond to what has been reported on the low concentration of organic matter and nutrients in liquid manure which makes it harder to recover the energy and nutrients [32].

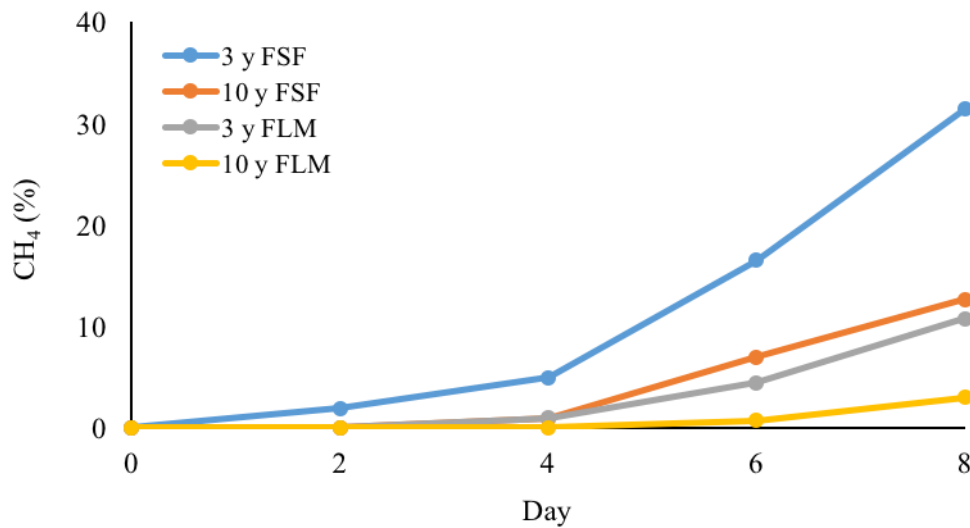


Figure 1. Methane emission ratio from manure mass for both stages.

Based on the one-way ANOVA analysis, there was significant difference in the measurement of CH_4 , emitted from FSF for both age stages ($p < 0.0001$). In addition to that, there was a significant difference between age stages and time ($p < 0.0001$), as emissions increased over time. The statistical analysis (Table 2) showed that the standard deviation at age of 3 years was (0.00) at T_0 but showed a significant difference at T_1 , T_2 , T_3 and T_4 .

Table 2. Statistical analysis for methane emission.

| Time / d | 3 y (FSF) | | 10 y (FSF) | | 3 y (FLM) | | 10 y (FLM) | |
|-----------|-----------|---------|------------|---------|-----------|---------|------------|---------|
| | Mean | Std Dev | Mean | Std Dev | Mean | Std Dev | Mean | Std Dev |
| $T_0 / 0$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| $T_1 / 2$ | 1.93 | 0.15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| $T_2 / 4$ | 4.93 | 1.30 | 0.89 | 0.33 | 0.95 | 0.95 | 0.00 | 0.00 |
| $T_3 / 6$ | 16.50 | 3.01 | 6.96 | 1.23 | 4.47 | 0.87 | 0.74 | 0.75 |
| $T_4 / 8$ | 31.41 | 0.96 | 12.67 | 3.65 | 10.79 | 2.99 | 3.02 | 3.02 |

3.2 Carbon dioxide emission

The recorded concentrations of CO_2 , emitted from manure mass were different in the two age stages (3 and 10 years) and in the manure storage method. For the FSF storage method, the minimum and maximum of mean ratio of CO_2 emissions for the gas samples were between T_0 (1.87 %) to T_4 (50.27 %) for age of 3 years which is higher compared to the age of 10 years from T_0 (1.13 %) to T_4 (32.09 %). As for the FLM storage method, the CO_2 emissions ratio for the gas samples were between T_0 (0.92 %) to T_4 (49.94 %) for age of 3 years but much lower for age of 10 years with only between T_0 (0.90 %) and T_4 (26.1 %) (Figure 2).

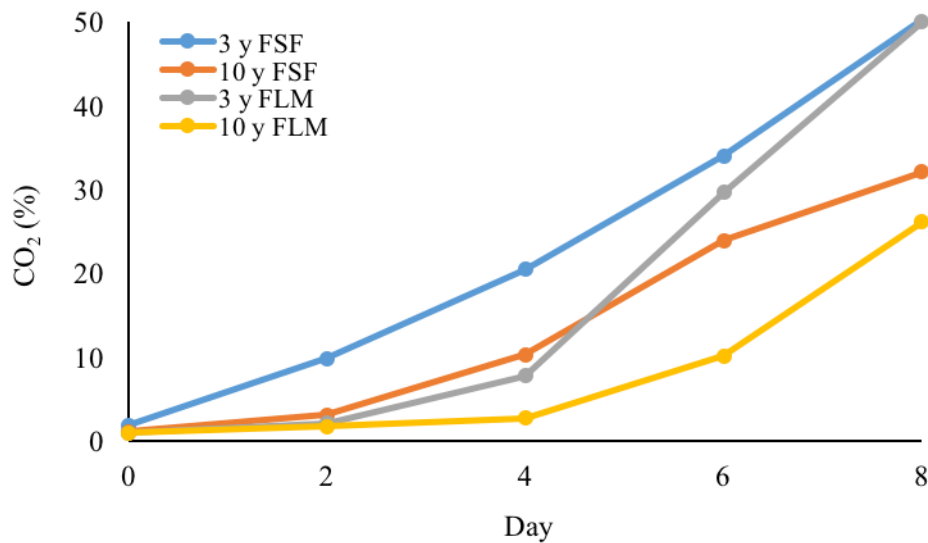


Figure 2. Carbon dioxide emission ratio from manure mass for both stages.

From the one-way ANOVA analysis, there were significant differences in the measurement of CO₂ emission from FSF at the two age stages in which the significance difference for both stages were ($p < 0.0001$). In addition, there were significant differences for the time and the interaction between age stages and time which was $p < 0.0001$ and $p < 0.0009$, respectively. The statistical analysis in Table 3 showed that the standard deviation of CO₂ emission from FSF at age of 3 years was relatively convergent at T₀ and T₃ while it showed significant difference for T₁, T₂ and T₄.

Table 3. Statistical analysis for carbon dioxide emission.

| Time / d | 3 y (FSF) | | 10 y (FSF) | | 3 y (FLM) | | 10 y (FLM) | |
|--------------------|-----------|---------|------------|---------|-----------|---------|------------|---------|
| | Mean | Std Dev | Mean | Std Dev | Mean | Std Dev | Mean | Std Dev |
| T ₀ / 0 | 1.87 | 1.03 | 1.13 | 0.11 | 0.92 | 0.43 | 0.90 | 0.91 |
| T ₁ / 2 | 9.77 | 2.71 | 3.05 | 1.06 | 2.10 | 0.82 | 1.71 | 1.71 |
| T ₂ / 4 | 20.45 | 0.09 | 10.24 | 0.47 | 7.74 | 2.05 | 2.71 | 2.56 |
| T ₃ / 6 | 33.98 | 1.04 | 23.91 | 4.21 | 29.60 | 1.48 | 10.09 | 7.09 |
| T ₄ / 8 | 50.27 | 5.96 | 32.09 | 5.22 | 49.94 | 2.91 | 26.10 | 4.56 |

The statistical analysis showed a difference in the standard deviation of CO₂ emission from FSF for the age of 10 years for all gas samples, in which the minimum and maximum of standard deviation were 0.11 at T₀ and 5.22 at T₄. Based on the one-way ANOVA, there was a significant difference of CO₂ emission measurement from FLM between the two age stages and the time ($p < 0.0001$). The standard deviation was also different at age 3 years for all gas samples, which were collected at regular intervals.

The study showed significant difference in carbon dioxide emission from dairy manure mass of FSF and FLM for both ages. This difference could be due to the major differences in pH and content of organic matter. Carbon dioxide is generated from the rapid hydrolysis of urea catalyzed by the urease enzyme and anaerobic fermentation of organic matter [33]. The results referenced the higher CO₂ concentration in the feces for both ages (3 and 10 years). It has been observed that CO₂ emission from FSF is more than that of FLM. Because of its porosity, FSF storage emits less methane than FLM as it lacks the anaerobic conditions needed for methanogenesis, reducing CH₄ emission. The amount of readily degradable carbon available for methanogenesis in FLM may be less than the amount of

carbon available for methanogenesis in FSF [34]. The deterioration of organic matter in the feces could also be a factor as the amount of fresh slurry feces is twice the amount of fresh slurry feces used in the liquid manure. This was consistent with the results reported by Mathot et al. [35] showed that CO₂ emission from the solid fractions were more than the liquid fractions.

However, there was also an increase in the level of CO₂ from FLM more than the FSF. This may be attributed by the pH differences of the manure in which pH of stored liquid manure is affected by the hydrolysis process of urea in urine. The variation in physiochemical characteristics affects the release of gas remarkably as well [33].

4. Conclusions

The study found that CH₄ and CO₂ emissions for the cows at the age of 3 years were higher than those at 10 years of age. Not only that, gases emissions from FSF were also higher than FLM for both age stages of 3 and 10 years due to the fact that the organic matter degradation in the feces and amount of fresh slurry feces is twice the amount of fresh slurry feces used in the liquid manure, as well as the organic matter in the manure mass for the age of 3 years is higher than for the age of 10 years. Overall, the results from this study can help to improve the current development of manure management practices in dairy farms. However, an evaluation on the mitigation strategies for reducing emissions and improving overall sustainability of dairy farms should be performed. Detailed data of manure systems are also needed in order to propose mitigation strategies for mitigating climate change and global warming.

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