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Comparison of CH_4 Emission Figures in Closed Chamber and IPCC Measurements in Rice Fields (*Oryza sativa* L.) with Different Flooding Rates

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Abstract

Greenhouse gas emissions CH_4 from paddy fields vary under different flooding systems and are often not fully represented by IPCC estimates. This study compared IPCC calculations with direct field measurements using the Closed Chamber and titration methods to obtain more accurate local emission values. The research was conducted in Tanjung Morawa District, Deli Serdang Regency (July-October 2025) using a survey method with purposive random sampling based on flooding systems (continuous flooding and intermittent irrigation). Emissions were observed across vegetative, generative, and harvest phases. The IPCC method produces CH_4 emission estimates that are approximately 1,39 times higher than those obtained using the closed chamber method. These discrepancies arise from the distinct approaches of the two methods: the IPCC method relies on standardized emission factors, resulting in more conservative estimates, while the closed chamber method measures fluxes directly at specific moments, making it more sensitive to daily field variations. During the generative phase, continuously flooded systems generate higher CH_4 emissions, whereas intermittent irrigation systems tend to reduce CH_4 release. This study provides locally validated CH_4 emission data that better represent actual field conditions and improve the accuracy of regional greenhouse gas inventories compared to default IPCC factors. Phase-based observations enhance understanding of temporal emission dynamics in rice cultivation. The findings recommend intermittent irrigation as an effective mitigation strategy to reduce CH_4 emissions, particularly during the generative phase, and encourage the integration of local field measurements into greenhouse gas reporting to support more accurate climate mitigation planning.

Keywords: Agricultural Emissions, Anaerobic Conditions, Global Warming Potential, Greenhouse Gases, Water Management

1. Introduction

Globally, the agricultural sector contributes 10–12% of total greenhouse gas emissions, dominated by CH_4 (67%), followed by N_2O (30%) and CO_2 (3%) (Djaja & Pasali, 2023). In the rice cultivation subsector, flooded paddy fields are major sources of CH_4 and CO_2 emissions, with emission levels influenced by the physical, chemical, and biological properties of submerged soils as well as the management practices applied (Qian et al., 2022; Chen et al., 2024). Flooded conditions create anaerobic environments that stimulate the activity of methanogenic and denitrifying microbes in decomposing organic matter, thereby promoting the release of CH_4 and CO_2 into the atmosphere (Jahangir et al., 2023).

The irrigation regime is a key factor influencing greenhouse gas emissions from paddy fields through the process of methanogenesis. Methanogenesis occurs under anaerobic conditions when soil redox potential decreases to approximately < –150 to –200 mV or when 70–80% of soil pore space is filled with water, indicating very low oxygen availability (Conrad, 2020). Anaerobic conditions stimulate methanogenic activity that produces CH_4, whereas partial soil drying allows oxygen to enter, enhancing oxidation and thereby reducing CH_4 production (Ariani et al., 2021). Continuous flooding in traditional rice cultivation requires substantial water inputs and leads to high CH_4 emissions

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(Rashid et al., 2024). As a mitigation strategy, the Alternate Wetting and Drying (AWD) system is applied because it can reduce water use and greenhouse gas emissions without compromising yield (Arouna et al., 2023). Oo et al. (2018) further confirmed that continuous flooding results in the highest CH_4 emissions, while AWD effectively suppresses them.

Previous studies have generally focused on either direct field measurements using the Closed Chamber method or estimations based on default IPCC emission factors. The increase in greenhouse gas emissions contributing to climate change and global warming has been widely reported in various studies (Dudung et al., 2022). In addition, the Closed Chamber method has been extensively applied to measure greenhouse gas fluxes directly in the field and is considered capable of representing actual conditions more accurately (Mazengo et al., 2024). Many studies emphasize the methodological accuracy of chamber techniques or evaluate greenhouse gas fluxes under specific water management systems. However, only a limited number of studies have directly compared IPCC-based calculations with simultaneous field measurements conducted at the same site and across different rice growth stages (Gallubally, 2000).

The novelty of this research lies in three main aspects. First, this study integrates direct CH_4 measurements (Closed Chamber methods) with IPCC estimation within a single research framework, enabling a quantitative comparison of the two approaches under real field conditions. Second, observations were conducted during the vegetative, generative, and harvest phases, providing phase-specific emission dynamics rather than merely seasonal averages. Third, this study examines differences in flooding systems (continuous flooding and intermittent irrigation) under tropical lowland rice field conditions, generating locally validated emission data and demonstrating the potential magnitude of overestimation associated with IPCC default emission factors.

Thus, unlike previous studies that typically apply a single method or rely solely on generalized emission factors, this research offers a comparative, growth phase-based, and site-specific evaluation that strengthens the scientific basis for improving regional greenhouse gas inventories and mitigation strategies in rice cultivation systems.

Given the considerations above, research needs to be carried out to assess the accuracy and suitability of CH_4 and CO_2 emission calculations obtained from direct field measurements using the Closed Chamber methods in comparison with the IPCC approach. This assessment will reveal how well the IPCC method reflects the real conditions of paddy fields in the study area.

2. Material and Methods

2.1. Research location

The study was conducted in Tanjung Morawa District, Deli Serdang Regency, titik koordinat 3°33'04.1"N 98°50'29.2"E dengan ketinggian tempat sekitar 25 mdpl (Figure 1). Soil analyses were performed at the Socfin Indonesia Laboratory and the Soil Biology Laboratory, Faculty of Agriculture, Universitas Sumatera Utara. Greenhouse gas analyses were carried out at the Laboratory of the Agricultural Environmental Assembly and Testing Center (BRMP Lingkungan) in Pati, Central Java. This research was conducted from July to October 2025.

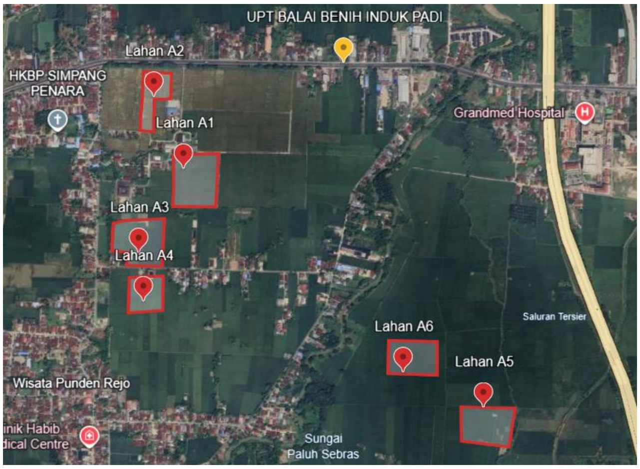

Figure 1. Sample collection point

2.2. Tools and materials

The tools used in this study included an acrylic chamber measuring 50 cm × 50 cm × 100 cm for collecting CH_4 gases; a thermometer to monitor temperature changes inside the chamber; a 20-ml syringe for sampling gas from the chamber; 10-ml vials for storing gas samples; a Micro GC 4900 equipped with a TCD (thermal conductivity detector). The materials used in this study were Ciherang rice variety, paddy soil samples, CH_4 gases.

2.3. Methods

This research employed a survey method. The selection of research sites was carried out using purposive random sampling based on the water management system in the paddy fields and the rice variety. The water management systems consisted of continuously flooded fields and intermittently irrigated fields, while the rice variety used was Ciherang. The study was conducted over one rice-growing season, covering the vegetative, generative, and harvesting phases. Furthermore, this study compares two different approaches for estimating CH_4 emissions, namely the closed chamber method and the IPCC calculation approach. The closed chamber methods provide direct, field-based measurements that capture actual gas fluxes under existing environmental conditions, whereas the IPCC method offers standardized emission estimates based on default factors.

2.4. Research Flowchart

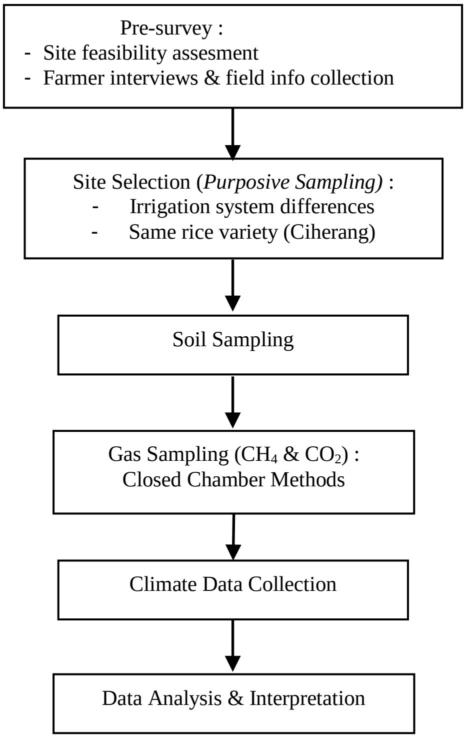

Figure 2. Research flow diagram

2.5. Field Sampling and Calculation of CH_4 Emissions Using the Closed Chamber Method

Samples of CH_4 gases were collected using the closed chamber technique (IAEA, 1993). Gas sampling was carried out manually using a closed chamber measuring 50 cm × 50 cm × 100 cm, constructed from acrylic sheets. The bottom edge of the chamber was designed to be inserted into the soil to prevent gas leakage. The chamber was equipped with a battery-powered fan to homogenize the air inside and a thermometer to record temperature changes. The thermometer was placed in a designated opening at the top of the chamber. Gas sampling was conducted three times during the rice-growing season, between 11:00 and 14:00 (Figure 3).

The chamber was positioned to enclose four rice clumps and kept level and airtight to avoid gas escape. Gas samples were withdrawn using a 10-ml syringe through a septum installed on the chamber lid. The lid was also equipped with a 9-volt battery-powered fan to mix the air inside and a thermometer to monitor internal temperature. Collected gas samples were then analyzed using a micro gas chromatograph (Micro GC CP 4900) equipped with a thermal conductivity detector (TCD). Ultra high purity (UHP) helium with 99.999% purity was used as the carrier gas.

The emissions of CH_4 obtained from the closed chamber measurements were calculated using the following equation:

with the following descriptions:

E = Gas emission (kg/m²/growing season)
V = Chamber volume (m³)
A = Chamber base area (m²)
T = Average air temperature inside the chamber (°C)
dCsp/dt = Rate of gas concentration change (ppm/minute)
Bm = Molecular weight of the gas under standard conditions
Vm = Gas volume at standard temperature and pressure (STP), equal to 22.41 liters

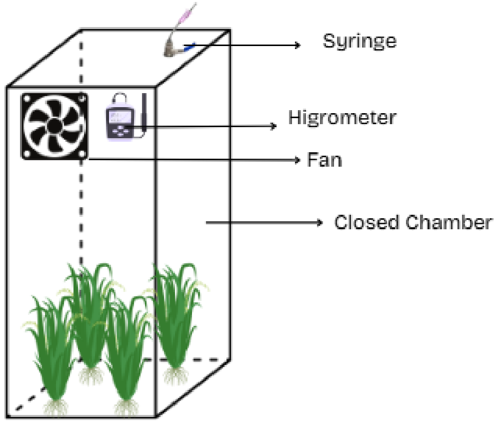

Figure 3. Collecting gasses using Closed Chamber Methods

2.6. Data Analysis

CH_4 emission data were tested for normality using the Shapiro–Wilk test to determine the appropriate analytical approach. Since the data were non-normally distributed, treatment differences were evaluated using the Kruskal–Wallis test. Correlation and regression analyses were applied to assess the relationships and contributions of the closed chamber, titration, and IPCC methods to the emission results. All analyses were performed using SPSS version 25.

3. Results and Discussion

3.1. CH_4 emission using closed chamber method

The measurements of CH_4 emissions under continuous and intermittent flooding reveal clear differences driven by water management and plant growth stages. During the vegetative phase, CH_4 emissions in both systems were very low or negative, reflecting the predominantly aerobic soil conditions that suppress methanogenesis. This suppression is strengthened by active CH_4 oxidation by methanotrophic bacteria (Win et al., 2022). Limited root exudates and underdeveloped aerenchyma further reduce CH_4 transport to the atmosphere (Rajendran et al., 2024).

In the generative phase, CH_4 emissions increased sharply under continuous flooding due to enhanced root exudation and stable anaerobic soil conditions that stimulate methanogenesis (Chaicana et al., 2018). The development of aerenchyma also promotes efficient CH_4 transfer from soil to the atmosphere (Senthilraja et al., 2023). Conversely, intermittent flooding produced mostly negative CH_4 fluxes because periodic soil aeration suppresses CH_4 formation through oxygen diffusion (Khatibi et al., 2024).

Table 1. CH_4 Emissions Under Different Flooding Systems at Each Growth Stage of Rice Using the Closed Chamber Method

Fields	Vegetatif Phase	Generative Phase	Tillering Phase	Total Emission
		(kg CH_4 /ha)		**(kg CH_4 /ha/musim)**
A1	-3.98	1556.68	4.77	1557.47
A3	-57.06	3.42	-12.38	922.89
A5	0.11	-142.56	54.26	-66.01
Average ± SD	-20,31 ± 31,89	472,52 ± 941,75	15.58 ± 34,60	804,78 ± 818,16
A2	-49.51	997.90	-25.50	-1361.86
A4	-12.41	-1387.17	37.72	-88.19
A6	25.13	-3.44	35.22	56.91
Average ± SD	-12,26 ± 37,32	-130,90 ± 1197,63	15,81 ± 35,80	-464,38 ± 780,62

[a] Note: A1, A3, A5 = fields with continuous flooding; A2, A4, A6 = fields with intermittent irrigation. Number of gas samples = 3 samples per location; 1 sample consists of 3 replications. Total gas samples per rice field location = 9 gas samples.

At harvest, CH_4 emissions declined sharply in both systems as root activity decreased and substrate availability became limited (Fang et al., 2019). Reduced aerenchyma function further constrained CH_4 release (Kim et al., 2018). Overall, continuous flooding enhanced CH_4 emissions due to persistent anaerobic conditions, while intermittent flooding substantially reduced CH_4 by promoting soil aeration (Win et al., 2021).

3.2. Comparison of CH_4 emissions between the closed chamber method and the IPCC method

The comparison of CH_4 emissions between the closed chamber method and the IPCC method shows substantial differences. The closed chamber method produces highly variable and extreme emission values (ranging from positive to negative), whereas the IPCC method yields more stable and consistent results across treatments.

Table 2. Comparison of CH_4 Emissions Using the Closed Chamber Method and the IPCC Method

Fields	CH_4 (Closed Chamber)	CH_4 (IPCC)	Closed chamber - IPCC	Ratio (%)
A1	1557.47	314.74	1242.73	494.84
A3	922.89	318.48	604.41	289.78
A5	-66.01	340.30	-406.31	-19.40
A2	-1361.86	144.78	-1506.64	-940.63
A4	-88.19	152.90	-241.09	-57.68
A6	56.91	144.78	-87.87	39.31
Average ± SD	170,20	236,83	-66.63	71,86% or 0,72 X IPCC > CC

[a] Note: A1, A3, A5 = fields with continuous flooding; A2, A4, A6 = fields with intermittent irrigation. Number of gas samples = 3 samples per location; 1 sample consists of 3 replications. Total gas samples per rice field location = 9 gas samples.

On average, CH_4 emissions measured using the closed chamber method (170.20 kg CH_4 /ha/season) are slightly lower than those estimated by the IPCC method (236.83 kg CH_4 /ha/season), with a difference of about –66.63 kg CH_4 /ha/season. This indicates that the IPCC method generally produces higher emission estimates compared to direct field measurements. The analysis (Figure 2a) shows that the relationship between the two methods is positive with moderate strength ($R^2 = 0.406$), although statistically insignificant ($p = 0.425$). The regression analysis resulted in a positive coefficient (6.710), indicating that increases in CH_4 emissions estimated by the IPCC tend to be followed by increases in CH_4 measured by the closed chamber method. However, the model's explanatory power remains low, as only 42.9% of the variation can be explained.

In continuously flooded fields, the closed chamber method produced much higher emissions than the IPCC method for A1 and A3, but yielded negative values for A5. In contrast, in intermittently flooded fields, most closed chamber measurements were negative, while the IPCC method consistently produced positive values, with very large differences, particularly in A2. This pattern shows that the closed chamber method is more sensitive to changing micro-environmental conditions and captures the dynamic processes of CH_4 formation and oxidation more accurately.

The differences between these two methods primarily stem from their methodological approaches. The closed chamber method is a direct field measurement influenced by microenvironmental conditions such as soil temperature, moisture, organic matter, and the activity of methanogenic and methanotrophic microorganisms (Lim et al., 2021). Meanwhile, the IPCC method uses standardized emission factors based on the assumption of homogeneous rice field conditions and reflects the maximum potential CH_4 production under anaerobic conditions (Nikolaisen et al., 2023; Rajendran et al., 2024). This leads the IPCC method to produce higher and more stable estimates. These findings are consistent with Jiang et al. (2019), who reported that IPCC-based estimations can overestimate CH_4 emissions by up to 193% compared to actual field measurements (Figure 3).

Figure 3. Research Documentation

4. Conclusion

The results show that irrigation systems play a crucial role in regulating greenhouse gas emissions in rice fields. Continuous flooding significantly increases CH_4 emissions, especially during the generative phase, whereas intermittent irrigation effectively reduces CH_4 release. This finding highlights water management as a practical and low-cost mitigation strategy for farmers.

In terms of methodology, the closed chamber method captures higher CH_4 emissions because it reflects real-time field fluxes influenced by microclimate and soil conditions, while the IPCC approach provides more conservative estimates based on standardized emission factors. The main advantage of this study is the clear comparison between field-based measurements and IPCC calculations under the same conditions, providing locally validated data.

It is recommended that farmers adopt intermittent irrigation to minimize CH_4 emissions, and that policymakers complement IPCC default factors with local measurement data to improve the accuracy of regional greenhouse gas inventories and climate mitigation strategies.

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