



RESEARCH ARTICLE

REVISED Rice plants reduce methane emissions in high-emitting paddies [version 3; peer review: 2 approved, 1 approved with reservations]

Previously titled: Rice cultivation reduces methane emissions in high-emitting paddies

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Abstract

Background: Rice is understood to enhance methane emissions from paddy fields in IPCC guidelines. However, rice actually has two opposite functions related to methane: i) emission enhancement, such as by providing emission pathways (aerenchyma) and methanogenetic substrates; and ii) emission suppression by providing oxygen pathways, which suppress methanogenesis or enhance methane oxidation. The overall role of rice is thus determined by the balance between its enhancing and suppressing functions. Although previous studies have suggested that rice enhances total methane emissions, we aimed to demonstrate in high-emitting paddy fields that the overall methane emission is decreased by rice plants.

Methods: We compared methane emissions with and without rice plants in triple cropping rice paddy fields in the Mekong Delta, Vietnam. The gas samples are collected using chamber method and were analyzed by gas chromatography.

Results: We found that rice, in fact, suppressed overall methane emissions in high-emitting paddies. The emission reductions increased with the growth of rice to the maximum tillering stage, then decreased after the heading stage, and finally recovered.

Discussion: Our result indicates that the overall methane emission is larger than that of rice planted area. In addition, although many studies in standard-emitting paddies have found that the contribution of soil organic matter to methanogenesis is small, prior studies in high-emitting paddies suggest that methanogenesis depended mainly on soil organic matter accumulated from past crops. The higher the methane emission level, the lower the contribution of the rice-derived substrate; conversely, the higher the contribution of the rice providing oxygen. Finally, rice plants reduce methane emissions in high-emitting

Open Peer Review

Approval Status ? ✓ ✓

	1	2	3
version 3			
(revision)		✓	✓
25 Jul 2019		view	view
version 2			
(revision)	?	?	?
27 Jun 2019	view	view	view
version 1			
29 Aug 2018	✗	?	?
	view	view	view

1. **Azeem Tariq** , Montpellier SupAgro-IRC, Montpellier, France
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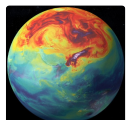
Any reports and responses or comments on the article can be found at the end of the article.

paddies.

Conclusion: The present study demonstrates that during the growing season, rice is suppressing methane emissions in high-emitting paddies. This means the significance of using the rice variety which has high suppressing performance in high-emitting paddies.

Keywords

Greenhouse gases, Mekong Delta, Methane oxidation, Methanogenesis inhibition, Rice paddy, Triple cropping



This article is included in the **Climate Action** gateway.



This article is included in the **Agriculture, Food and Nutrition** gateway.

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Author roles: **Oda M:** Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Writing – Original Draft Preparation, Writing – Review & Editing; **Nguyen Huu C:** Resources, Writing – Review & Editing

Competing interests: No competing interests were disclosed.

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REVISED Amendments from Version 2

References were indicated more clearly and distinguished from our assumptions.

A simple explanation was added to the word “ebullition”.

Introduction: We added the reason for “epochal”.

Abstract: The reason of the methanogenesis source was corrected to follow the discussion section.

Abstract: The interpretation of the phenomena was added in the discussion.

Methodology: Methodology: The numeric mistype of the number of paddy fields “18” was corrected to “3”, and related expression “several” was corrected to “conventional”.

Result and discussion: We added the study location with hyperlink of google map.

Result and discussion: We added statistical analysis and the interpretation for the effect of the measurement locations.

Conclusion: We added the content of which had been stated in discussion and abstract.

English words and grammatical errors were corrected.

See referee reports

Introduction

The role of rice in methane (CH_4) emissions changes according to emission levels. Because, rice performs three key functions related to CH_4 emissions: i) providing a CH_4 pathway through a well-developed system of intercellular air spaces (aerenchyma), ii) providing a substrate for methanogenesis, and iii) oxidizing CH_4 in rhizosphere by supporting O_2 counter-transport through aerenchyma system^{1–6}. The level of contribution of these functions varies with the overall emissions, and the total amount of CH_4 emitted to the atmosphere is thus a balance between CH_4 production and oxidation⁶. To the best of our knowledge, rice enhances overall CH_4 emissions from paddy fields. In addition, previous studies have mostly disregarded a potential impact of overall emission levels on the role of rice in enhancing or suppressing CH_4 emissions.

Cicerone and Shetter measured CH_4 emissions with a closed chamber on the water surface of a paddy field, and found that 4 hours after starting measurement, CH_4 concentration was 290 ppm over rice plants and only 4 ppm over open water¹. Further studies have revealed that CH_4 produced under methanogenesis diffuses through the soil, which is oxidized by the surface barrier before reaching the atmosphere^{2,7}. Rice absorbs diffused CH_4 from its roots and emits CH_4 through aerenchyma^{3,5,7}. These facts suggest that CH_4 is not emitted from the soil without rice. Other recent studies have provided additional evidence that the primary source of CH_4 is current-season photosynthates—specifically, root exudates or decaying tissues^{8–11}. This results in CH_4 emissions that peak during the late stage of rice growth. Thus, the presence of rice plants has been determined to be the cause of CH_4 emissions in paddy fields.

Wassmann *et al.*¹² measured CH_4 emissions on the water surface of a paddy field amended with organic matter. They found

that organic matter incorporation increased total CH_4 emission levels from 27–90 to 160–240 kg CH_4 ha⁻¹ crop⁻¹, and the direct emission from soil by ebullition increased from 15–23% to 35–62%, respectively¹². Since it is known that organic matter incorporation causes CH_4 emissions to peak during the early stages of rice growth¹², when the rice is still small and the aerenchyma is not well developed, the results of Wassmann *et al.*¹² should be closely examined to determine whether ebullition increased with total emissions. According to the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines, CH_4 emissions for 100 days of rice cropping are 130 kg CH_4 ha⁻¹ crop⁻¹; however, emissions were observed at almost twice this value by Wassmann *et al.*¹² Average CH_4 emissions from rice paddies in Asia without and with organic matter incorporation ranged from 16 to 200 and 250 to 500, respectively¹³. Although ebullition has been little studied¹⁴, we think ebullition must occur at the high emission levels. Furthermore, in the study by Wassmann *et al.*¹², twin CH_4 emissions peaks appeared, with an early peak corresponding to the organic matter amendment and a later peak corresponding to rice-originated substrate¹². An alternate interpretation of these results is that the twin peaks could reflect the oxidation performance of rice, since CH_4 oxidation is known to increase with rice growth, up to the maximum tillering stage, and then decrease¹⁵.

We monitored CH_4 emissions in the paddy fields for 5 years (total 15 crops) in triple rice cropping fields in the Mekong Delta, Vietnam. The CH_4 emission level was an order of magnitude higher than IPCC standards. These high CH_4 emissions suggest that ebullition must have been occurring. We hypothesized that rice plants decrease overall methane emission based on the extremely high emission levels. It will be epochal if present the fact that rice plants decrease overall methane emission in paddy fields; because, rice is believed enhancing overall CH_4 emissions from paddy fields.

Results and discussion

We compared CH_4 emissions with (Rice) and without rice (No Rice) on the water (soil) surface of triple cropping rice paddy fields in the Mekong Delta. Our results showed that rice presence decreased CH_4 emissions by half of No Rice. The effect of rice was large even in the early growth stage because of the high plant density (230 kg ha⁻¹ in dry weight; approximately 3 cm interval) and the rapid growth in the tropical climate (see Figure 1, Figure 2). Although the high CH_4 emission is shown in the first week, it is considered to be caused by the erratic character of ebullition. In fact, there was no difference in the emission between Rice and No Rice on both the 7th and 9th day (see Figure 1). The difference of the total emissions between the treatments is significant ($p=0.013$; one-sided Welch's t-test). More importantly, the treatments have formed each group (Figure 2). This supports the difference caused by not the locations but the treatments. The p-value is 0.013 if the difference made by location. Complete, unprocessed data are available on figshare¹⁶. There was no marked CH_4 emissions peak in the late-stage of the rice mentioned in previous studies^{8–11}. This suggests that the amount of methanogenesis from the rice-derived substrate is relatively small. Note the high emission levels

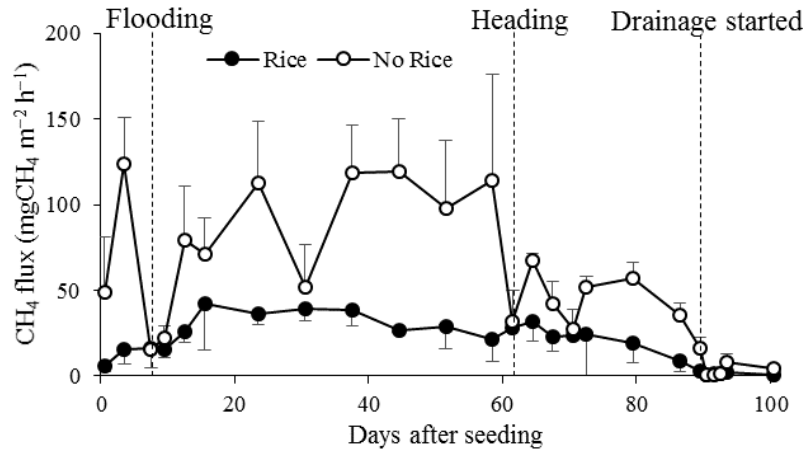


Figure 1. Seasonal CH₄ emissions in paddy fields. Average CH₄ emissions of rice-planted areas and no-rice-planted areas in triple cropping rice fields in the Mekong Delta. Winter–Spring season (2017). The paddy fields did not receive rice straw incorporation. Error bars are s.d. (n = 3).

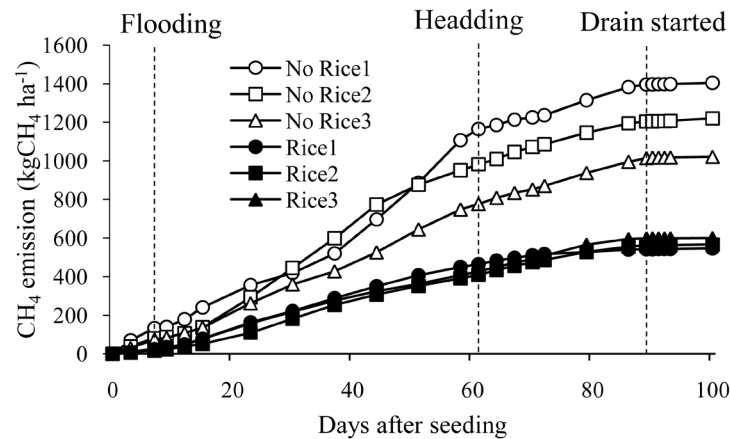


Figure 2. Cumulative CH₄ emissions in paddy fields. Cumulated CH₄ emissions of rice-planted areas and no-rice-planted areas in triple cropping rice fields in the Mekong Delta. The number in the legend relates to the fields.

(500–1400 kg CH₄ ha⁻¹ crop⁻¹). These findings suggest that total CH₄ emissions are reduced by oxidation or methanogenesis inhibition associated with growing the rice plant.

We also found that the reduction rate of CH₄ emissions increased with the growth of the rice plant. The CH₄ reduction rate was calculated using a moving average of five values by the following formula.

$$\text{reduction rate} = (\text{No Rice} - \text{Rice}) / \text{No Rice}$$

The rate peaked at maximum tillering stage, then bottomed at after heading stage, and then recovered (see Figure 3). The decrease around the heading stage was caused partially by an increase of emissions in rice-planted areas, and mainly by a decrease of emissions in the unplanted area.

No consensus has yet been reached on the extent to which methanotrophs or rice roots attenuate CH₄ emissions¹⁷. Using

the N₂ atmosphere technique, CH₄ oxidation ratios have been found to be around 40% on average and were relatively stable throughout the rice growing season¹⁷. However, genuine CH₄ oxidation, as measured using inhibitors, tend to decrease with rice growth, and the reduction rate for total CH₄ emissions can reach up to 20%¹⁷. Although, most of those studies assume plant-mediated transportation¹⁷, in general, our results roughly matched the results using the N₂ atmosphere technique. This suggests that the reduction in CH₄ emissions is not due to genuine oxidation and is more likely to be due to methanogenesis inhibition by oxygen from aerenchyma, which lasts until harvesting¹⁸.

We found high CH₄ emissions in unplanted paddy fields of which not incorporate organic materials. Despite this lower input of methanogenesis substrate, CH₄ emission levels were 12 times higher than the IPCC guidelines. The emission levels remained almost stable after reaching a maximum. This suggests that

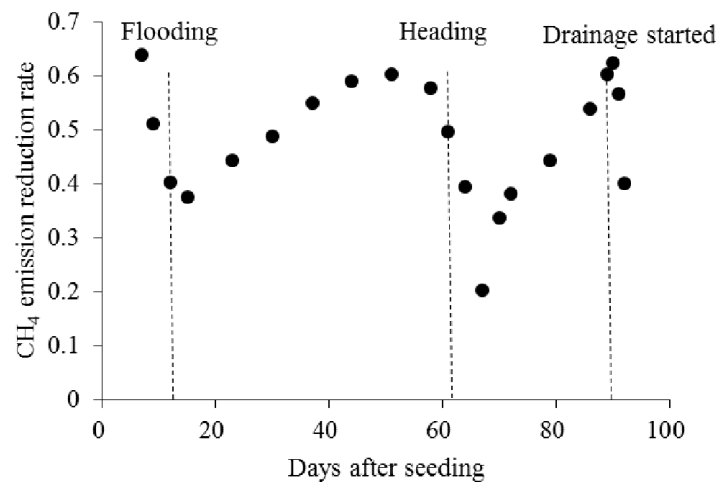


Figure 3. Reduction rate of CH₄ emissions. The CH₄ reduction rate was calculated by (No Rice – Rice)/No Rice.

methanogenesis at our site mainly depends on soil organic matter that has been accumulated from past rice crops. Prior studies have suggested that the contribution of soil organic matter to methanogenesis is small; however, these studies also indicated that higher emission levels tend to be associated with higher contribution rates of soil organic matter^{8–11,19}. Furthermore, a recent study found that large rice plants reduce CH₄ emissions compared to small rice plants in paddy fields with high soil C contents; instead, they show the opposite effect in paddies with low soil C contents²⁰. Thus, our results are consistent with prior studies that assume that emission levels are proportional to the amount of soil organic matter which can be a methanogenesis substrate.

High-emitting paddies of CH₄ emissions, which exist widely across tropical Asia¹³, would have substantial soil organic matter stock formed by sequential rice cropping under flooded conditions²¹. For instance, the use of a rice variety which has better performance of methanogenesis inhibition in high-emitting paddies is very effective; the 10 % reduction is equivalent to 100% of methane emission in standard paddy fields. On the other hand, without rice plants, the methane emission from the existing soil organic matter stock will double by ebullition; the 100% increase is equivalent to 1000% of the standard paddies. This suggests that the future study for the soil organic matter stock map is critical.

Conclusion

To our knowledge, most studies of CH₄ emissions in paddy fields have been conducted in fields with low overall emission levels. Since the role of rice in CH₄ emissions varies according to the overall emission levels, these results cannot be appropriately generalized to rice paddies with high emission levels. The results of our study suggest that rice reduces emissions in high-emitting paddies. This means the significance of using the rice variety which has high suppressing performance in high-emitting paddies. The emission levels are related to the amount of soil organic

matter which can be a methanogenesis substrate; this suggests that the future study for the soil organic matter stock map is critical.

Methods

Study site

Experimental fields were in Tan Loi 2 Hamlet, Thuan Hung village, Thot Not district, Can Tho city, Vietnam. Farmers conduct triple rice cropping by direct seeding and full flooding. This district receives almost 2 months of a flood annually from the Mekong River. The flood decomposes rice straw underwater to the extent that it is no obstacle for seeding. Therefore, farmers start the rice cropping by leveling the fields, without incorporating rice straw. We observed CH₄ emissions in three paddy fields (26 × 17 m each) under conventional conditions for 5 years from September 2011. A preliminary study was conducted with the rice variety OM501 (suitable for the season) in the Summer-Autumn season of 2016 by the same methods and paddies of the present study (see Figure 4). In the present study, we used the three fields for replication. We conducted the present study after the annual flood (4 November 2016–12 February 2017); these fields did not incorporate rice straw because of the period was after the annual flood.

Treatment

We compared CH₄ emissions with (Rice) and without rice (No Rice). We set 2 × 2 m squares of plastic films on a part of each three fields just before seeding, then carefully removed them with seeds on the films immediately after seeding. In other points, there was no difference with farmers' conventional rice-growing procedures. Farmers scattered 230 kg ha⁻¹ (in dry weight) of germinated rice seed (variety Jasmine) on drained wet paddy fields' surfaces on 5th November. This wet condition was maintained for 7 days, then the fields were kept flooded until 89 days after seeding (DAS), and the rice harvested on 100 DAS. The farmers applied fertilizer, which included 76 kg of urea on 12 November, 53 kg each of urea and NPKS (16-16-8-13),

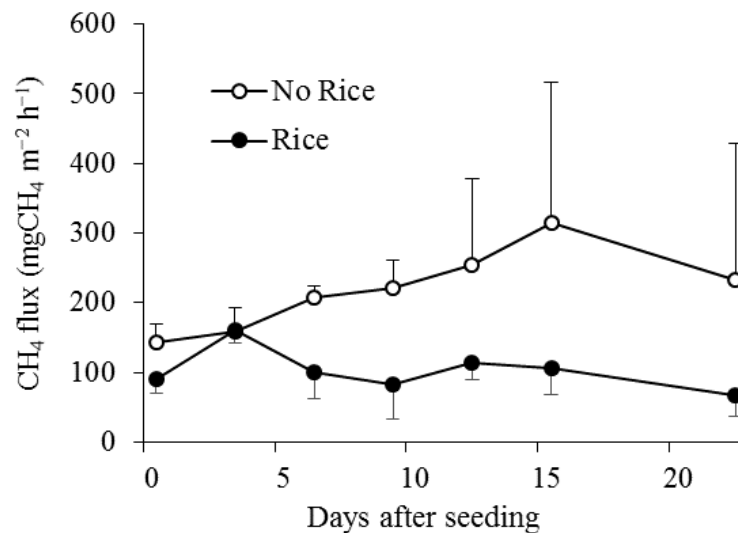


Figure 4. Seasonal CH₄ emission in paddy fields. Average CH₄ emissions of rice-planted areas and no-rice-planted areas in triple cropping rice fields in the Mekong Delta. Summer–Autumn season (2016). The paddy fields received incorporated rice straw of the previous crop. Error bars are s.d. (n = 3).

diammonium phosphate on 19 November, and 53 kg each of urea and NPKS on 15 December. The daily average water levels were monitored with water level loggers (HOBO U20; Onset Computer Corporation, Bourne, Massachusetts) at the corner of the fields, and the average levels were 2.0 cm (−0.6 to 6.1 cm) until drained.

Measurement of CH₄ emissions

We set an approximately 2 m long and 0.5 m wide ladders from the center of the shorter bund to allow measurement of CH₄ without touching the paddy soil surface. Those ladders were on the borders of the non-planted areas in each field. We set PVC chamber bases on the paddy fields of both sides of the ladders to avoid measurement perturbation. Chambers (60 × 80 cm and 100 cm high, transparent acryl) were set on a watertight chamber bases for every measurement. Measurements were taken at 8 a.m. because previous research has indicated that emissions at this time have a high correlation (ca. 90% of average emission) with average daily emissions²². We mixed the air in the chamber with a fan for 5 min after setting the chamber, then sampled the first gas, then sampled the second gas 20 min later. We conducted the measurements once a week throughout the rice

growing stage, but every 3 days for 2 weeks after seeding, heading stage, and around draining. The samples were analyzed by gas chromatography (GC-14B, Shimadzu, Kyoto). The cumulative CH₄ emissions were calculated by linear interpolation.

Ethics statement

This study was conducted with the approval of the farmer.

Statistical analysis

Data were processed using Microsoft Excel 2016.

Data availability

Raw data of this article is available from figshare: <https://doi.org/10.6084/m9.figshare.6916277.v1>¹⁶. Data are available under the terms of the [Creative Commons Zero “No rights reserved” data waiver](#) (CC0 1.0 Public domain dedication).

Grant information

The author(s) declared that no grants were involved in supporting this work.

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[Reference Source](#)

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Current Peer Review Status: ? ✓ ✓

Version 3

Reviewer Report 15 August 2019

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Kees Jan van Groenigen 

Department of Geography, College of Life and Environmental Sciences, University of Exeter, Exeter, UK

The manuscript has further improved and it seems scientifically sound. Based on these standards, the manuscript can be accepted for indexing. However, the quality of the writing still leaves something to be desired; the text is quite hard to follow at times and it still contains several grammatical errors. I've made some suggestions before, but I don't have time to point out all grammatical errors in each new version.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Agronomy, biogeochemistry, greenhouse gas fluxes.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 25 July 2019

<https://doi.org/10.5256/f1000research.22008.r51631>

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Dung Duc Tran

Center of Water Management and Climate Change (WACC), Vietnam National University – Ho Chi Minh City (VNU – HCM), Ho Chi Minh City, Vietnam

The authors have revised the manuscript based on my comments. It is now accepted for indexing.

Thanks.

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 2

Reviewer Report 09 July 2019

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Dung Duc Tran

Center of Water Management and Climate Change (WACC), Vietnam National University – Ho Chi Minh City (VNU – HCM), Ho Chi Minh City, Vietnam

The manuscript has been improved based on the comments. However, I recommended the authors to consider the following 2 points before approval for indexing:

1. The authors replied: "We corrected the method section and clarified the details. For the site location map, we think it can be found on the internet nowadays.". I do not agree, please add the Figure because the common audience doesn't have much time to find the location.
2. Conclusion is not quite sufficient in terms of relating to previous findings.

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 22 Jul 2019

Masato Oda, Japan International Research Center for Agricultural Sciences, Tsukuba, Japan

Thank you for the comment.

1. For the site local map:

We added the link to the Google map according to the article guidelines of F1000Research. The link takes no time for the reader of F1000Research, in addition, it's scalable.

2. Conclusion:

We added a conclusion which was presented in the abstract but not presented in Conclusion sections. The aim of the present study is the role of rice in the paddy field for methane emission in the historical context. Therefore, we mentioned it in the first sentence of the abstract as "Rice is understood to enhance methane emissions from paddy fields", then concluded it in the Conclusion as "To our knowledge, most studies of CH₄ emissions in paddy fields have been conducted in fields with low overall emission levels. Since the role of rice in CH₄ emission varies according to the overall emission levels, these results cannot be appropriately generalized to rice paddies with high emission levels."

Competing Interests: No competing interests were disclosed.

Reviewer Report 05 July 2019

<https://doi.org/10.5256/f1000research.21593.r50481>

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Azeem Tariq 

UMR 951 Innovation SupAgro-INRA-CIRAD, Montpellier SupAgro-IRC, Montpellier, France

I have checked the authors' report. It is hard to follow the changes made by authors in the new version. Further, the authors have not justified all the points raised in my first report.

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 22 Jul 2019

Masato Oda, Japan International Research Center for Agricultural Sciences, Tsukuba, Japan

Thank you for reconsidering our manuscript. The methodology is described in the first sentence of the 'Results and discussion': "We compared CH₄ emissions with (Rice) and without rice (No Rice) on the water (soil) surface of triple cropping rice paddy fields in the Mekong Delta". Our treatment is only "with" or "without" rice, the other condition is the same as farmers' conventional. See the second sentence in the 'treatment' of 'Methodology' section: "We set 2 × 2 m squares of plastic films on a part of each three fields just before seeding, then carefully removed them with seeds on the films immediately after seeding. In

other points, there was no difference in farmers' conventional rice-growing procedures."

Other responses are as follows:

1. Water management:

The water management is full flooding. See the second sentence of the 'Methods' section: "Farmers conduct triple rice cropping by direct seeding and full flooding."

2. Justification of the first-week emission:

See the third sentence of the 'Results and discussion': "Although the high CH₄ emission is shown in the first week, it is considered to be caused by the erratic character of ebullition. In fact, there was no difference in the emission between Rice and No Rice on both the 7th and 9th day (see Figure 1)." Furthermore, we added the following sentence: "The difference of the total emissions between the treatments is significant (p=0.013; one-sided Welch's t-test). More importantly, the treatments have formed each group (Figure 2). This supports the difference caused by not the locations but the treatments. The p-value is 0.013 if the difference made by location." In addition, supplemental figure 4 is the supporting data.

3. Input straw:

Both no input. See the fourth sentence of the 'Methods' section: "The flood decomposes rice straw underwater to the extent that it is no obstacle for seeding. Therefore, farmers start the rice cropping by leveling the fields, without incorporating rice straw."

4. Conclusion section:

You can see the conclusion section.

Competing Interests: No competing interests were disclosed.

Reviewer Report 04 July 2019

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Kees Jan van Groenigen 

Department of Geography, College of Life and Environmental Sciences, University of Exeter, Exeter, UK

While this revised version has improved, I still have some issues with this manuscript. Importantly,

the comments by reviewer 1 weren't all fully addressed. Moreover, the manuscript contains *many* statements that are not supported by any references, and ideas that are not adequately explained. For instance:

- 2nd to last sentence of the introduction: Who is "our"? Your paper tries to prove the opposite, so "our" is not "we". Do you mean "It is generally assumed that rice enhances overall CH₄ emissions from paddy fields."? In that case, please add a reference to support this statement.
- 2nd paragraph of introduction: "Therefore, an established theory has emerged that CH₄ is not emitted from the soil without rice." This statement needs a reference.
- Page 3, top of right column. First time you mention "ebullition". The text hasn't explained yet what this means, and how important this process is for overall CH₄ emissions.
- Page 3, top of right column: "Since it is known that organic matter incorporation causes CH₄ emissions to peak during the early stages of rice growth". Reference needed.
- Page 3, right column: "Although ebullition has been little studied, ebullition must occur at high emission levels." Why? Please explain and provide references.
- Page 5, left column: "High-emitting paddies of CH₄ emissions, which exist widely across tropical Asia...". Reference needed.
- First sentence of the conclusion: "Most studies of CH₄ emissions in paddy fields have been conducted in fields with low overall emission levels." Again, no reference provided. A reference to a review article showing that this is true would help.

The text is unclear in several places. For instance:

- Abstract: "our results in high-emitting paddies suggest that methanogenesis depended mainly on soil organic matter accumulated from past crops." How did you come to this conclusion?
- Abstract: "The higher the methane emission level, the lower the contribution of the rice-derived substrate". How does this interpretation follow from your own results?
- Last sentence of introduction: "It will be epochal if present the fact that rice plants decrease overall methane emission in paddy fields." The meaning of this sentence is unclear.
- Results, line 9: Why is "ebullition" between quotation marks?
- Page 4, left column, top paragraph: "The decrease around the heading stage was caused partially by an increase of emissions in rice-planted areas, and mainly by the erratic emissions in the unplanted area." If this decrease is erratic, then how can we be sure that the high emissions earlier in the growing season aren't erratic as well? How can we be sure that high emissions before planting in the unplanted plots are not erratic?
- Page 5, top of right column: "We observed CH₄ emissions in 18 paddy fields (26 × 17 m each) under several conditions for 5 years from September 2011." Where are these data

reported? If you don't report them, then why mention this? The earliest data that are reported in this manuscript are from 2016.

- Page 5, top of right column: "In the present study, we used three fields for replication." Are these fields the same fields that were described above (i.e. 26*17 m in size)? This is not clear.

The article still contains quite a few grammatical errors or poor structure. A few suggestions:

- Abstract, methods section: Delete "of" to write "methane emissions with and without rice plants".
- Last sentence of intro: "We hypothesised that rice plants decrease overall methane emission based on the extremely high emission levels."
- First sentence of the results section would be a good place to mention study location.
- 2nd sentence of results: "Our results showed that rice presence decreased CH₄ emissions by half."
- Page 4, right column: "This suggests that methanogenesis at our site mainly depends on soil organic matter that has been accumulated from past rice crops."
- Last paragraph of results section: Change "huge" to "large", or "substantial", and provide references to support this statement.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Agronomy, biogeochemistry, greenhouse gas fluxes.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 22 Jul 2019

Masato Oda, Japan International Research Center for Agricultural Sciences, Tsukuba, Japan

Thank you very much for your kind suggestion. Furthermore, thank you so much for correcting and improving the English. We completed the lack of references.

We revised the manuscript for the other points as follows:

1. Page 3: The explanation of "ebullition".

We added the words "the direct emission from soil by".

2. Introduction: The reason of epochal.

We added as follows: "; because, rice is believed enhancing overall CH₄ emissions from paddy fields".

3. Abstract: The reason of the methanogenesis source.

We correct as follows: "our results" to "prior studies".

4. Abstract: "The higher...How does this interpretation...?"

Thank you for leading. We changed the last part as follows: "; conversely, the higher the contribution of the rice providing oxygen. Finally, rice plants reduce methane emissions in high-emitting paddies."

5. Results, line 9: Why is "ebullition" between quotation marks?

We deleted.

6. Page 4, left column, top paragraph: The explanation of erratic.

We changed to "a decrease of".

7. Page 5, top of right column: 18 paddy fields...

We corrected "18" to "3", and "several" to "conventional".

8. Page 5, top of right column: The field size.

It is the same size because of the same fields. We think it is obvious by the above correction for the number of fields.

9. To mention the study location in the results section.

Competing Interests: No competing interests were disclosed.

Version 1

Reviewer Report 14 June 2019

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**Dung Duc Tran**

Center of Water Management and Climate Change (WACC), Vietnam National University – Ho Chi Minh City (VNU – HCM), Ho Chi Minh City, Vietnam

The authors of "Rice cultivation reduces methane emissions in high-emitting paddies" present an interesting manuscript with great effort to demonstrate the balance between rice's emitting and suppressing function changes according to overall methane emission levels. In general, the manuscript is well-written. However, I recommend the authors to do a major revision to the

manuscript before being potentially accepted for indexing by the Journal.

1. The Introduction section should add research objectives or in terms of research questions that help readers to promptly understand the paper's content.
2. In the Methods section, description and activities are needed in more detail; additionally a map of the case study would be useful.
3. In the Results and Discussion section, I expected more discussion that enhance more work on comparing findings with previous studies. In addition, the limitations and future outlooks need to be elaborated upon.
4. A Conclusion is important to add into the manuscript since it presents the real implication of the research based on the authors' perspective.

Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and is the work technically sound?

Partly

Are sufficient details of methods and analysis provided to allow replication by others?

Partly

If applicable, is the statistical analysis and its interpretation appropriate?

Yes

Are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions drawn adequately supported by the results?

No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Hydrology and Agricultural Water Management

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 17 Jun 2019

Masato Oda, Japan International Research Center for Agricultural Sciences, Tsukuba, Japan

Thank you very much for your precious suggestions.

1. We improved the abstract and the introduction to describe more clearly the aim of this

study.

2. We corrected the method section and clarified the details. For the site location map, we think it can be found on the internet nowadays.

3. We added the latest reference which is expected to give readers the deeper understanding of our findings to the result and discussion section.

4. For the limitations and future outlooks, we described them at the end of the discussion section and the newly added conclusion section.

See the revised manuscript, please.

Competing Interests: No competing interests were disclosed.

Reviewer Report 28 May 2019

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Kees Jan van Groenigen 

Department of Geography, College of Life and Environmental Sciences, University of Exeter, Exeter, UK

Oda and Chiem present CH₄ fluxes from Vietnamese rice paddies with- and without rice plants, and conclude that the presence of rice plants reduces CH₄ emissions. Their results are interesting and convincing, and the experimental design seems solid. That said, I have several serious reservations about this paper that need to be addressed before it can be approved.

1. The authors need to explain more clearly the relevance of their research. It might be true that the presence of rice plants reduces CH₄ emissions, but the *sole purpose* of paddies is to support rice agriculture. Thus, the statement that rice cultivation reduces methane emissions from paddies seems a bit strange. Does the IPCC provide estimates of emissions from rice paddies without rice plants? If not, how exactly would the results from this study contribute to understanding the contribution of rice agriculture to CH₄ emissions?
2. The experimental design does not allow the authors to test their hypothesis as stated in the abstract. The authors aim to demonstrate that the effect of rice plants on methane emissions depends on the background emissions (i.e. without plants). However, the authors only test the effect of rice plants in paddies with high background emissions.
3. The authors did not test the significance of differences between plots with- and without rice plants.
4. The reference list is quite outdated; only 2 of the cited studies were published in the last 5 years. Several relevant recent papers are ignored by the authors. For instance, Jiang *et al.* 2017¹ reported that in paddies with high soil C contents, large rice plants reduce CH₄ emissions compared to small rice plants. Furthermore, they show the *opposite* effect in paddies with low soil C contents. Please note that I am a co-author on that paper; I don't

suggest that the authors need to include it, but please consider this as just one example of relevant recent research.

5. The first sentence of the introduction is essentially an hypothesis. Yet, the authors provide no clear support to back up this statement.
6. In the last sentence of the introduction, what does “all studies” refer to? The studies 1-6? Did these studies compare CH₄ emissions with and without rice plants? This is not clear.
7. The text is slightly confusing in some places. For instance, in the “background” section in the abstract it’s not clear whether the authors refer to methane emissions with or without rice plants. The same is true for the last paragraph of the introduction. On page 4, second paragraph, the discussion of changes in “reduction rates” is quite confusing. Does a decrease in reduction rates mean means relatively low or high rates in plots with plants?
8. Some basic info about the field site is missing. For instance, MAT and MAP data would be useful, as well as soil C contents.
9. I spotted a few grammatical errors. For instance, in the background section of the abstract, “existing studies” should be “previous studies”. In the discussion section of the abstract “rice-providing” should be “rice-derived”. The first sentence of the results and discussion section should read “In the present study, we compared CH₄ emissions on the water (soil) surface of paddy fields with and without rice”. These are just a couple of examples. Perhaps the authors could contact a native speaker to have a quick look at their paper?

References

1. Jiang Y, van Groenigen KJ, Huang S, Hungate BA, et al.: Higher yields and lower methane emissions with new rice cultivars. *Glob Chang Biol*. **23** (11): 4728-4738 [PubMed Abstract](#) | [Publisher Full Text](#)

Is the work clearly and accurately presented and does it cite the current literature?

No

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?

No

Are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions drawn adequately supported by the results?

Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Agronomy, biogeochemistry, greenhouse gas fluxes.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 14 Jun 2019

Masato Oda, Japan International Research Center for Agricultural Sciences, Tsukuba, Japan

1. Thank you for your precious suggestion! We changed the word "cultivation" to "plants" in the title. We think the word is more suitable to the content.
2. Thank you again. We aim to demonstrate rice plants are suppressing overall methane emission in high CH₄ emission paddy fields. We changed the last sentence of the background as follows. "that the balance..." to "that the overall methane emission is decreased by rice plants." We expect that this change clarifies some other points that you indicate. In association with, we think the experiment in the low background is not necessary because they have been conducted by plenty of studies.
3. We think it's obvious from Figure 1 and 2; for your information, the p-value by one-sided Welch's t-test for the total emissions is 0.013.
4. Thank you very much for introducing the study to support our conclusion. We referred to that in the last paragraph of the discussion. We have referred to rather old-dated studies because we aim to mention the role of rice in the context of the history of the study for paddy fields CH₄ emission.
5. The sentence indicates common sense; therefore, we would like to change as follows: "Rice is understood to enhance methane emissions from paddy fields as mentioned in IPCC guidelines."
6. We would like to change the sentence ", all studies ... these studies". to "rice enhances overall CH₄ emissions from paddy fields. In addition, previous studies".
7. We added the formula, and we clarified the sentences in the results section.
8. We think the soil carbon contents is important; however, that is out of range of this study and we don't have the map.
9. Thank you so much! We had used an English editing service, but that was not enough. We have revised the English.

Competing Interests: No competing interests were disclosed.

Reviewer Report 09 May 2019

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 **Azeem Tariq** 

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The authors of "Rice cultivation reduces methane emissions in high-emitting paddies" present an effort in collecting and measuring the CH₄ emissions, in three rice cropping cycles during the 100 days of the field experiment. The overall paper has been written in good English and in a logical manner. The major concern in this manuscript is the methodology and conclusion. The methodology is not clear enough, for example the authors do not make clear the explanation of water treatments in fields with rice and without rice. The authors claimed lower CH₄ emissions due to absence of rice plants, but the difference in the first week (Fig. 1) after seeding when there will be hardly any significant role of rice seedlings is not justified.

Furthermore, the methodology section is much confusing with the use of decomposition of straw and addition of straw (study site section). It is hard to follow the inputs of straw in fields with and without rice. The authors clearly need to modify the methodology section to make the description of treatments and to justify the results.

Further, there are no conclusions drawn from the manuscript. The authors forgot to give the conclusion at the end of manuscript.

In general, the manuscript is not acceptable in its current condition.

Is the work clearly and accurately presented and does it cite the current literature?

No

Is the study design appropriate and is the work technically sound?

Partly

Are sufficient details of methods and analysis provided to allow replication by others?

No

If applicable, is the statistical analysis and its interpretation appropriate?

No

Are all the source data underlying the results available to ensure full reproducibility?

Partly

Are the conclusions drawn adequately supported by the results?

No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Greenhouse gas monitoring in agricultural systems.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Author Response 21 May 2019

Masato Oda, Japan International Research Center for Agricultural Sciences, Tsukuba, Japan

Thank you very much for reviewing our manuscript and giving precious comments.

I think your comments can be summarized to three points: "uniformity of conditions", "the effect of early stage rice plants", and "the reason of high CH₄ emission in the first week".

1) For the first, we would like to apologize for the incomplete explanation and mistype in the treatment subsection that leads readers to misunderstanding for the above points. The sentences and the correct version are as follows:

"We set 2 × 2 m squares of plastic films on each field" → "We set 2 × 2 m squares of plastic films on a part of each three fields"

"In other plots, there was no difference with farmers' conventional" → "In other points, there was no difference with farmers' conventional"

These corrections will make clear that the experiment was conducted under completely uniformed conditions of three pair. These corrections are also the answer for the suspicion of uniformity of conditions.

2) For the second, we think the effect of rice is large even in the early growth stage of rice because of the high plant density (230 kg ha⁻¹) and the rapid growth of them. We would like to apologize again for mistype of the unit.

3) For the third, we think the high CH₄ emission in the first week was caused by the erratic character of "ebullition". You can check there is no difference between "no rice" and "rice" in the 7th and 9th day's emission by raw data (<https://f1000research.com/articles/7-1349/v1#ref-16>).

For straws, this is not a treatment but the conventional management of triple cropping rice cultivation in Mekong Delta. They were decomposed in the natural flooding water and not incorporated into the soil (however, straws were incorporated in the preliminary study).

Following the editorial team's recommendation, we are waiting for additional peer review reports before starting on any article revisions.

Competing Interests: No competing interests were disclosed.

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