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Reply on RC2

Naima Iram et al.

Author comment on "Soil greenhouse gas fluxes from tropical coastal wetlands and alternative agricultural land uses" by Naima Iram et al., Biogeosciences Discuss., https://doi.org/10.5194/bg-2021-28-AC2, 2021

RC1

Thank you for the invitation to review this manuscript. I have found the paper interesting and enjoyed learning about the study system. The paper is ambitious and presents management recommendations that would be of relevance to policymakers and land users. I have made comments and suggestion, which are listed below, aiming to support the authors in their ambition to offer evidence-based management solutions to coastal wetlands.

Author's response: We thank Anonymous referee#2 for constructive feedback. The received comments were carefully considered, and revisions were made accordingly to improve the quality of the manuscript. Specifically, we have highlighted the strengths and limitations of our conclusions and how this information can guide future measurements of greenhouse gas emissions in different land uses. We acknowledge that land use replication was limited (one site per land use), but we wanted to focus on tackling small scale variation (five chambers per plot) and, importantly, temporal variation (seasonal- 3 seasons for two years). In total, we collected 237 samples in four sampling campaigns during June 2018- February 2020 that showed that land use, followed by temperature and rainfall, were affecting greenhouse gas fluxes. Future studies should aim at focusing on replication on land use.

We have included a point-by-point response to comments raised by the reviewer, and a revised manuscript has been submitted.

- The last part of the sentence about financial incentives does not follow logically from the first part. Please rephrase.

Author's Response:

We have rewritten as follows:

P2-L25: “Converting agricultural land, particularly wet ponded pasture, to tidal wetlands could provide large GHG mitigation.”

- L34-36 Clunk sentence, please rephrase.
- L37 … favour emission of potent greenhouse gases (GHG), e.g. CH_4 and N_2O

Author’s Response: We have rewritten the introduction to improve its clarity. This paragraph was improved as follows:

L31-36. “Coastal wetlands are at the interface between terrestrial and marine ecosystems, accounting for 10% of the global wetland area (Lehner and Döll 2004; Yang et al. 2017). They are highly productive and provide various ecosystem services such as water quality improvement, biodiversity, and carbon sequestration (Lal, 2008; Duarte et al., 2013; Mitsch et al., 2013). For instance, mangroves can accumulate five times more soil carbon compared to terrestrial forests (Kauffman et al., 2020, Mcleod et al., 2011; Sjögersten et al., 2014). However, the high productivity and anoxic soil conditions that promote carbon sequestration can also favour emissions of potent greenhouse gas (GHGs), including CO_2, CH_4 and N_2O (Whalen, 2005; Conrad, 2009).

- L44 Reference needed.

Author’s Response: Reference was added.

L39-40. The emission of CO_2 is a result of respiration, where fixed carbon through photosynthesis is partially released back into the atmosphere (Oertel et al., 2016).

- L48 convoluted sentence, please improve sentence structure

Author’s Response: The sentence was improved as follows:

L43-45. “Thus, the total GHG emissions from a wetland is the result of environmental conditions that favour these microbial processes, all of which result in highly variable emissions from wetlands worldwide (Kirschke et al., 2013; Oertel et al. 2016).”

- L51-53 References needed

Author’s Response: Reference Knox et al. (2015) was added to L48.

- L54-55. References needed

Author’s Response: Reference Rashti et al. (2015) was added to L59-60.

- L66-77 Sentence does not flow well from the previous statement.

L66-67 Can you please make this nuanced to reflect that it is the balance between process rates and the area over which they occur determines the importance of tropical regions net emissions.

Author's Response: We have rewritten the paragraph as follows:

L47-57. Despite potential high GHG emissions from coastal wetlands, these are likely to be lower than those from alternative agricultural land uses (Knox et al., 2015), which emit GHGs from their construction throughout their productive life. Firstly, when wetlands are converted to agricultural land, the oxidation of sequestered carbon in the organic-rich soils release significant amounts of CO_2 (Drexler, de Fontaine, & Deverel, 2009; Hooijer et L, 2012; Ciais et al., 2013). Secondly, removing tidal flow and reverting coastal wetlands to freshwater ecosystems, such as during the creation of ponded pastures or dams and agricultural ditches, results in high CH_4 and N_2O emissions (Deemer et al., 2016; Grinham et al., 2018; Ollivier et al., 2019; Peacock et al., 2021). Artificial ditches and drains in agricultural landscapes are also sources of CH_4 emissions, contributing ~ 0.2-3% of the total anthropogenic CH4 emissions globally (Peacock et al., 2021). Finally, the use of N fertilisers causes increased N_2O emissions (Rashti et al., 2015). Emissions of GHG from land-use change can be mitigated through various management activities in wetlands, for instance, through reduction of fertiliser use and the reinstallation of tidal flow on unused agricultural land (Rashti et al., 2016; Kroeger et al. 2017).

- L83-85 This sentence is not clear to me. Can you please improve the flow of the text?

Author's Response. We clarified the sentence in the revised introduction as highlighted below:

L58-63. In this study, we measured the annual GHG fluxes from different land-use types, including natural coastal wetlands (freshwater tidal forest, saltmarsh, and mangroves) and agricultural lands (a sugarcane plantation and a ponded pasture) in tropical Australia. The objective was to assess the difference within these land uses in GHG emissions throughout different seasons that characterise tropical climates (hot and wet vs cool and dry). This data will inform emission factors for the conversion of wetlands to agricultural land uses and vice versa, filling in a knowledge gap that has been identified in Australia (Baldock et al., 2021) and in tropical regions worldwide (IPCC 2013).

- You need to explain the rationale for high emissions during high tides. In the intro, you agree that more sulphate reduces $CH_{4.}$ These points seem contradictory to me.

Author's Response: Thanks for highlighting this. We omitted the contradictory information from the revised introduction. We have clarified in the methods section as follows:

L97-100. The main objective of the manuscript was to assess the effects of land-use change, including variations within seasons. Additionally, the effects of tidal inundation were assessed to confirm that our measurements in mangroves and saltmarsh (the ones most affected by tides) were not strongly affected by the time of sampling (low vs high tide).

- Four or three sampling events? This is a bit unclear to me. Is it correct that you measured during different tides only once? You need to consider if that is enough in the context of seasonally. The tidal impacts are a bit unclear to me; from the final sentence in the introduction, it sounds to me that all of the wetlands are impacted by tides? Please clarify this.

Author's Response: As explained above, the measurements of low vs high tide was just a one-time additional experiment to verify that tide was not strongly affecting our sampling design. Mangroves and saltmarshes are the sites that were directly affected by tides; hence, they were the focus of our tidal effects experiment. The freshwater tidal forests are indirectly affected, as high tides can push groundwater into the forest. We have clarified this in the method section and deleted this statement from the main hypothesis in the Introduction.

- I suggest you swap the order of section 2.2 and 2.3 as you refer to the gas chromatography set up in the current section 2.2

Author's Response: Thanks for the suggestion, but we think that the current order goes well with the flow of information. Section 2.2 refers to a gas isotope ratio mass spectrometer (L-121), not a gas chromatograph (L145).

- Section 2.3.

You need to include some detail on the spatial distribution of your samples. What is the size of the sampled area, and how did you determine if it is representative of other systems with similar land use? I have the feeling that there is a risk of pseudoreplication, but I cannot assess that without some more detail. Suppose you have subsamples within the same area rather than independent replicate samples from each land-use class that need to be reflected in your conclusions. If you do not have independent replicates, you do not have the statistical basis for making statements relating to land use, and you can only state that the sites are different, so you need to be much more cautious in your recommendations in the discussion.

What method was used for the randomisation?

Author's Response:

We added details on the spatial distribution of the sampling area in revised Figure 1 (P6-L113).

We acknowledge the limitation of this study in terms of land use replication. For this study, we wanted to focus on addressing the small-scale variability of each land use and temporal variations. Furthermore, land-use level replication of our studies was limited due to inaccessibility of these sites due to permission for access into farms, adverse weather during most of the year (e.g. during very hot conditions or during flooding), safety risk due to crocodiles and the high cost of sample analysis (>$AUD 8,000 per experiment). We described this in the discussion section:

L320-323. The GHG fluxes in our study represented the difference between the sites due to the limitation of our studies in time and space because of the inaccessibility of these sites during most of the year; however, we tried to increase the robustness of our experiment by focussing on small scale variation (five chambers per site) and importantly, time variation (seasonal- 3 seasons for two years).

- How did you deal with areas with vegetation?

Author's Response:

We did not place incubation chambers on vegetation where possible because our objective was to measure GHG emissions from the soil. This was elaborated in the methods section as follows:

L130-132. On each sampling date, five chambers were installed at random locations ~ 5cm deep in the soil a day before taking samples (Rashti et al., 2015). The chambers were placed on areas without vegetation because our objective was to measure GHG emissions from the soil. However, below-ground roots that obstructed with collar installation were cut.

- What number of gas samples were collected from each chamber after the initial tests? During with season, did you test for linearity?

Author's Response:

Four samples were collected from each chamber at 0, 20, 40 and 60 minutes to measure the linearity of the GHG fluxes over time. However, for GHG flux calculations, we collected two samples from all five chambers at 0 and 60 minutes. Linearity was tested for all chambers during dry-hot seasons and one chamber per site for all other seasons. Our previous experience with this method has taught us that this is the most cost-effective way to measure GHG from wetlands (Kavehei et al., 2021) and agricultural lands (Rashti et al., 2015). Linearity results were provided in supplementary files (S2). We clarified this in the manuscript as follows:

L156-160. For the sampling period during the hot and dry season (21 ☐ 29 October 2018), gas samples were collected at 0, 20, 40 and 60 minutes from all chambers to perform a linearity test for measuring increase or decrease in the concentration of the gas with time. For subsequent experiments, a linearity test was performed on subset chambers for each site (Rashti et al., 2016), and an R^2 value of > 0.7 was recorded for all tested samples with a linear trend for CO_2, CH_4 and N_2O over the experimental period (S2).

- I think you may well have impacts of ebullition of CH4; there are signs of that in Figure 2. If you could not test for linearity for CH_4 fluxes, especially during the flooded period, your fluxes may not be correct.

Author's Response:

Yes. Methane ebullition effects were reflected in the wet pasture ecosystem through high emissions, and these sites were flooded during most of the year. We measured the linearity of one chamber in each site for three days in the flooded period to present precise fluxes, and the R^2 value was ranged between 0.6-0.9. This was described in the manuscript as following:

L158-160. For subsequent experiments, a linearity test was performed on subset chambers for each site (Rashti et al., 2016), and an R^2 value of > 0.7 was recorded for all tested samples with a linear trend for CO_2, CH_4 and N_2O over the experimental period.

- Some of your areas look as if they have standing water; how did you sample gas fluxes on these? Did you use floating chambers? Please add more detail about the sampling.

Author's Response: Our sites in mangroves, saltmarsh and ponded pasture ecosystem had always standing water; however, the water was never deep enough to require floating chambers. Therefore, we used the static chambers but with the lateral holes opened to allow water movement and with vertical extension to avoid full submersion. We have added the details in the manuscript as follows:

L100-102. We carried out GHG measurements with static chambers, which had lateral holes that could be left covered with rubber bungs at low water levels and left open at high water levels to allow water movement. During high tide measurements, vertical extensions of the PVC chambers were used to avoid submersion.

- Your statistics are not clear to me. Please add some more detail to make it clear how you analysed for variation and interactions between the two main factors in your study site and season.

Author's Response:

Variation and interactions between the two main factors, e.g., site and season, were analysed through the Kruskal-Wallis test, and Mann-Whitney U Test when data did not comply with the assumptions of normality and one-way Analyses of Variance (ANOVA) was used for normally distributed data to analyse the difference between sites and seasons. Details were added in the manuscript as follows:

L167-174. When data were not normal, they were transformed (log, 1/x) to comply with the assumptions of normality and homogeneity of variances. Despite transformations, some variables were not normally distributed; thus, the differences between sites and seasons were analysed with the non-parametric Kruskal-Wallis test and Mann-Whitney U Test. The data which met the normality assumptions were analysed for spatial and temporal differences with one-way Analyses of Variance (ANOVA), where site and season were the predictive factors and replicated (gas chamber) was the random factor of the model. Additionally, a Pearson correlation test was run to evaluate the correlation of GHG with measured environmental factors.

- what is the assumption of w=17.38 for each season based on? This needs to be justified in the context of seasonal climate data.

Author's Response:

On the basis of 40 years of climate data on mean maximum temperature and rainfall from the Bureau of metrology Australia (Bureau of Meteorology, http://www.bom.gov.au/jsp/ncc/cdio/cvg/av), we assumed that each season consisted of ~17.38 weeks. The source file was attached as a supplementary file (S3).

- What is the number of temporal replicates within each season n=1?

Author's Response:

Within each season, we measured each site for at least three days. This was described in the methods section as following:

L93-94. We conducted measurements for three days for each land use and ecosystem type within each season (Livesley et al. 2009) except for the first sampling during the dry-cool period of 2018, when only mangroves, saltmarsh and sugarcane were surveyed for one day.

- Is table 3 the same data as in Figure 2? If so, I suggest not showing the same data twice. If different, please make captions and table headings clearer to help the reader understand the data.

Author's Response:

Thanks for the suggestion. Table 3 was excluded from the revised manuscript and added as a supplementary file (S4)

- L281-285 Here, you are repeating results in the discussion. I suggest you focus this part of the text on comparing and contrasting to other studies.

Author's Response:

This section was modified to provide the trends to compare and contrast with literature. The manuscript was modified as follows.

L250-256: A significantly lower CH_4 emissions in natural wetlands and very high GHG emissions across the agricultural land use types in our study area confirm our hypothesis that coastal tidal wetlands, even freshwater ones, can be a viable land-use to reduce GHG emissions from current agricultural land. The GHG emissions from wetlands have an extensive range. For CO_2, fluxes can range between −139 and 22,000 mg m^{-2} d^{-1} (Stadmark and Leonardson 2005; Morse et al. 2012), for CH_4, from −1 to 418 mg m^{-2} d^{-1} (Allen et al. 2007; Mitsch et al. 2013; Cabezas et al. 2018), and for N_2O, from −0.3 to 3.9 mg m^{-2} d^{-1} (Hernandez and Mitsch 2006; Morse et al. 2012). The GHG fluxes measured in this study were within the lower end, with ranges from -1191 to 10, 970 mg m^{-2} d^{-1} for $CO_{2,}$ from −0.2 to 3.9 mg m^{-2} d^{-1} for $CH_{4,}$ and −0.2 to 2.8 mg m^{-2} d^{-1} for N_2O.

- L290 You state here that temperature is a driver of the fluxes you measured, but your stats do not support this, i.e. no significant effect, so I don’t think this point is valid in the light of your results.

Author’s Response: Yes, the point was clarified in the revised paragraph as follows:

L258-260. The GHG emissions varied with season, with an overall increase in emissions during the hottest and wettest time of the year, but neither temperature nor other measured factors were a significant predictor of any of the measured GHGs. However, the emissions of CO_2 and N_2O were highest when temperatures were > 38°C.

- L298 All your chambers were dark – I do not get the point of this statement. Why single out mangroves.

Author’s Response:

Thanks for highlighting this point. The statement was excluded from the revised manuscript.

- High CH_4 emissions during the hot-dry season – How dry were the soil? Or were they sit wet in the high emitting sites?

Author’s Response:

That is correct. All measured sites in coastal wetlands and wet ponded pasture were always wet, even during the hot-dry season.

- I think the paper needs to include some data in the environmental conditions measured in the different seasons to understand what conditions the microorganisms were experiencing.

Author’s Response: We included the detailed information on the environmental factors and GHG emissions as a supplementary file because none of the measured main influencing factors (including temperature, rainfall, water-filled pore space and bulk density) was correlated with GHG emissions. We mentioned in the manuscript as following:

L243-248- Overall, we found not one single parameter could explain GHG emissions from all sites except land-use. The CO_2 emissions were not significantly correlated to bulk density (R^2 =0.026 p = 0.918 n=18), % WFPS (R^2 =-0.003 p = 0.99 n =18), or soil temperature (R^2=0.296 p = 0.233, n =18). Similarly, soil CH_4 emissions were not correlated with bulk density (R^2 = -0.096 p = 0.706 n =18), % WFPS (R^2 = 0-.224 p = 0.372, n =18) or soil temperature (R^2 =0.286 p = 0.25 n=18). Finally, no correlation was found between N_2O emissions and bulk density (R^2= -0.349 p = 0.156 n =18), % WFPS (R^2= -0.34 p = 0.168 n =18), or soil temperature (R^2= -0.241 p = 0.335 n =18) (S4).

- Management implications section

Since I do not think you have independent replication (at least I cannot determine if you do from the methods section) makes it hard to make strong conclusions about land use. As I mentioned earlier, you can only state that you have differences between sites but not link these differences specifically to land use as another site-specific effect may cause these differences.

Author's Response: Following your suggestion, the conclusions were modulated by modifying the discussion section as following:

L327-330. The GHG fluxes in our study represented the difference between the sites due to the limitation of our studies in time and space because of the inaccessibility of these sites during most of the year; however, we tried to increase the robustness of our experiment by focussing on small scale variation (five chambers per site) and importantly, time variation (seasonal- 3 seasons for two years).

L338-343. Within the sampled sites, land use seemed the highest predictor of the GHG fluxes found in this study. This result suggests that restoration of wet ponded pastures and sugarcane to coastal tidal wetlands, even freshwater tidal forests, could mitigate total GHG emissions (CH_4+ N_2O) derived from agricultural activities. Of especial interests are ponded pastures, which, when wet, can have GHG emissions with values 200-fold than any other land use. If these high emissions are persistent in other sites, ponded pastures could provide an opportunity to reduce emissions through land use management practices. These incentives could financially benefit farmers and provide additional co-benefits derived from coastal wetland restoration.

- In the discussion, I think it is important to consider if your space for time model is valid, i.e. is it plausible that the current agricultural system would revert to function as the natural system you measured fluxes from? This needs careful discussion as ecosystem restoration does often not take you back to the starting point, or at least it can take a long time for the restored system to regain its original functions.

Author's Response:

The potential for GHG mitigation for changing agricultural lands to wetlands is promising; however, there is still uncertainty of whether degraded land can be successfully reverted to wetlands. It is likely that, instead, a new type of ecosystem could be created (Hobbs et al. 2009), and that legacy of land use could last for years (Ardon et al. 2017). However, this study suggests that this potential should be further explored in similar land uses in tropical regions. Additionally, future monitoring of newly created wetlands would provide information on whether and when the full GHG mitigation can be achieved through wetland creation or restoration.

- L304-309 You have not measured these parameters, so you can only speculate that they cause low emissions. The way this statement is phrased suggests your study has demonstrated this, which is not the case. Please rephrase.

Author's Response: The paragraph was rephrased as follows:

L269-278. The relatively low CH_4 emissions from all the natural wetlands could be attributed to the presence of terminal electron acceptors like iron, sulphate, manganese and nitrate, which result in low rates of methanogenesis (Fumoto et al., 2008; Kögel-Knabner et al., 2010; Sahrawat, 2004). Although not measured in this study, it is likely that sulphate reducing bacteria outcompete methane-producing bacteria (methanogens) in the presence of high sulphate concentrations in tidal wetlands, resulting in low CH_4 production. Additionally, competition between methanogens and methanotrophs (CH_4 consuming bacteria) could result in a net balance of low CH_4 production despite freshwater conditions (Maietta et al. 2020).

- Describe how you calculate your CO_2eq in the methods section and present this in the results before discussing these data.

Author's Response:

We described the CO_2eq calculation method in the methods section as following:

L160-163. For comparing GHG effects of CH_4 and N_2O fluxes, $CO_{2\text{-equivalent}}$ ($CO_{2\text{-eq}}$) were calculated by multiplying CH_4 and N_2O fluxes to global warming potentials of 25 and 298, respectively (IPCC 2007). It must be noted that GHG fluxes represented radiative balance in our study, as recently suggested by Neubauer S.C. (2021).

- Plant mediated emissions of CH_4 and N_2O are likely to be important in your system. As this would impact your overall conclusion regarding the global warming potential of the different sites, I think you need to discuss this.

Author's Response:

This is a good point. The following information was added to discuss the suggested point.

L281-293. Recent studies have shown that some plant species could reduce CH4 emissions (Jeffrey et al. 2021), so CH4 fluxes in the present study could underestimate the actual CH4 mitigation potential of the studied wetlands. Contrarily, some plant species, e.g. rice paddies (Timilsina e al., 2020) and *Miscanthus Sinensis* (Lenhart et al., 2019), can be N_2O sources. Therefore our N_2O fluxes were conservative.

- After reading the manuscript, I think that although it presents novel data, I do think it is premature to use the manuscript in its current form as a basis for management recommendations.

Author's Response:

We appreciate your feedback to improve the present version of the manuscript. We tried our best to incorporate the suggested revisions. We have highlighted in the manuscript the limitations of our sampling and modified the management recommendations and conclusions accordingly.

Please also note the supplement to this comment:
https://bg.copernicus.org/preprints/bg-2021-28/bg-2021-28-AC2-supplement.pdf