Answers to feedbacks from Reviewer 1

We would like to thank sincerely reviewer 1 for her/his comments that help improve our manuscript (BGD-2023-102). We have indicated below our replies to the comments of reviewer 1. When we mentioned the line numbers, where revisions are made, these line numbers are in the revised manuscript without the tracked changes.

1.1. The authors present a nicely written study on the effect of reduced fertilization rates in combination with mechanical weeding on GHG fluxes in an industrial oil palm plantation in Indonesia. I support the publication subject to revision detailed below IF all points can be addressed. Hopefully it is just a case of clarification and not serious flaws in the study design.

Thanks for your time and helpful comments that improve our manuscript.

1.2. My main points are that you need to clarify early on that your presented CO_2 fluxes are from chambers and likely not soil respiration as the enclosure time was too long for that. Please clarify whether there was vegetation present in the chambers or soil only. This needs to be caveated throughout, especially when you compare your results to studies that measured 'proper' soil respiration.

The method of soil GHG measurement was clearly stated in section 2.2 first sentence. Also, please see our answers to reviewer 1's questions #1.6 and #1.10 below.

We added the sentence "Any aboveground vegetation inside the chambers was carefully cut during the study period but root and litter remained as normal" (lines 148-149 of the revised manuscript).

1.3. Please clarify your measurement regime around the fertilisation period. It is not clear whether measurements were more frequent after fertilisation (which they should have). Otherwise your interpretation of fluxes due to fertilisation might be flawed and cannot be accepted for publication in its current form. To characterise peak N2O emissions after fertilisation, daily measurements are needed initially and frequent measurements at least over two weeks until fluxes are back to background levels. Otherwise no sounds cumulative emissions from a fertilisation event can be determined.

We have characterized in details the peaks of soil N_2O emissions following fertilization in our earlier studies in both smallholder and large-scale oil palm plantations (Hassler et al., 2017; Meijide et al., 2020). From our previous studies, we knew that the peaks of soil N_2O emissions occurred within 2 weeks following fertilization. Thus, as stated in the second sentence of section 2.2., we conducted the measurements in the palm circles (with 2 chambers in each of the 16 replicate plots) within 2 weeks following the fertilization (lines 140-141 of the original manuscript). Fertilization was conducted only twice a year (in April and October of each year; line 116 of the original manuscript), and because fertilization was only twice a year, sampling schedule that employed frequent measurements following fertilization did not show significant differences in soil N_2O emissions as compared to one sampling schedule that captured the peak of N_2O emission within 2 weeks following fertilization (please see Hassler et al., 2017 – first paragraph under section 4.3).

We agree with the reviewer 1's comment that capturing the peak of N_2O emission is important, and we have captured these peak emissions with our one measurement period within 2 weeks following fertilization, as stated in the original manuscript: line 223, Fig.

S2, line 232, Table 1, lines 235-236, Fig. 2. We argue that it is important that our sampling design not only captured the N_2O peak from fertilization (Fig. S2) but more importantly also represented the spatial variation brought by management practices, representing the fertilized palm circle (only 18% of the area), unfertilized inter-row (67% of the area) and frond-stacked area (15% of the area) (Fig. 2). As we have discussed in the last paragraph of section 4.2, the short-term fertilization effect may not be the most important in determining the annual N_2O emission in this mature oil-palm plantation but instead the long-term legacy effects (more than a decade) of conventional high fertilization, prior to the start of this management experiment. The 3-4 years of reduced fertilization did not yet affect the soil N_2O fluxes, as also supported by the comparable mineral N levels between conventional and reduced fertilization (Table 2).

Moreover, we would like to point out that our measurement period (July 2019-June 2020) fell during the prolonged covid-19 lockdown (March 2020-May 2022) in Indonesia. There were huge logistical difficulties in continuing our original plan of conducting intensive measurement following fertilization, for validation of our previous findings. Despite the lockdown, we managed to continue the measurement regime to capture the N_2O peak within 2 weeks following fertilization on the palm circle (Fig. S2) and all the rest of the study year with monthly measurement as permitted during the lockdown (i.e. reduced number of physical presence of personnel) – 16 plots × 2 subplots/plot × 3 management zones/subplot (palm circle, inter-row, frond-stacked area).

Our data are valuable as there had been no full accounting of soil GHG fluxes from spatially replicated management experiment in a large-scale oil palm plantation.

1.4. L22 add ‘for’ after accounted

We added “for” after accounted.

1.5. L149/150 & L173 change to the ‘University of Goettingen’

Thank you for pointing this out. We changed “Goettingen University” to “University of Goettingen”

1.6. L138 Did your chambers include vegetation or just soil? This particularly important to interpret the soil CO2 fluxes. You can’t call them ‘soil respiration’ later on (e.g. l 299) if some of the chambers contained vegetation or litter such as palm fronts. A better term to use might be soil efflux or ecosystem respiration?

Our chambers had no aboveground vegetation inside but the roots and litter were left as in normal condition. It is wrong to use ecosystem respiration because ecosystem is both heterotrophic and autotrophic (roots and aboveground plant respiration; Malhi et al. 1999). We think soil respiration is appropriately used for chamber-based measurements that include both root and heterotrophic respiration (as roots remain at depths in the soil even if the aboveground vegetative parts inside the chamber are carefully cut-off). Please also see our answers to reviewer 1’s question #1.10 below (Trumbore, 2006; see Figure below).

Nonetheless, in order to accommodate the reviewer 1’s concern, we now used ‘soil CO_2 efflux’ to replace soil respiration all throughout the revised manuscript.

1.7. L140 How frequently did you measure after fertilisation? Did you measure more frequently after the fertilisation? It is not clear at the moment as figure S2 only shows monthly measurements. There is a risk you are over-interpreting your results if you only measured once after application.

Please see our answers to question #1.3 above.

1.8. Section 2.4 (L176 to L197) Please write out the equations with an equation editor, number them and then refer to them in the text. It would make it a lot clearer to see which equations have been used and what the parameters within one equation are.

Thanks for your suggestion. But before reading below, please see also section 2. 1 second paragraph to refresh the experimental plot design. We addressed this suggestion of reviewer 1 by rewriting this part with equations.

First, the net primary production (NPP) was determined. Within the inner 30 m × 30 m area in each replicate plot (Fig. 1b), all the palms were measured for their stem height, harvested fruit weight, and the number of pruned fronds during 2017–2020 (Iddris et al., 2023). Aboveground biomass per palm was calculated using the allometric growth equation of Asari et al. (2013). Annual aboveground biomass production per palm is the difference in aboveground biomass between two consecutive years, averaged over a two-year period (2018-2019 and 2019-2020).

Aboveground biomass C production (g C m^{-2} yr^{-1}) = annual aboveground biomass production per palm (kg $palm^{-1}$) × planting density (142 palms ha^{-1}) × tissue C concentration (0.41 g C g^{-1}) × 10^{-1} (for unit conversion) (1)

Fruit biomass C production (g C m^{-2} yr^{-1}) = annual fruit harvest per palm (kg $palm^{-1}$, mean of 2019–2020) × planting density × tissue C concentration (0.63 g C g^{-1}) × 10^{-1} (for unit conversion) (2)

Frond litter biomass C input (g C m^{-2} yr^{-1}) = annual litter production per palm (kg $palm^{-1}$, mean of 2019–2020) × planting density × tissue C concentration (0.47 g C g^{-1}) × 10^{-1} (for unit conversion) (3)

NPP (g C m^{-2} yr^{-1}) = Aboveground biomass C production + Fruit biomass C production + Frond litter biomass C input + Root biomass C production (140 g C m^{-2} yr^{-1}; Kotowska et al. 2015) + Root litter biomass C input (45 g C m^{-2} yr^{-1}; Kotowska et al. 2015) (4)

Second, the net ecosystem productivity (NEP) was calculated following Malhi et al. (1999) and Quiñones et al. (2022) for agricultural land use.

NEP (g C m^{-2} yr^{-1}) = heterotrophic respiration – (NPP – fruit biomass C) (5)

Our measured soil CO_2 fluxes included both autotrophic and heterotrophic respirations. We assumed 70% heterotrophic contribution to soil CO_2 efflux, based on a long-term quantification in a forest in Sulawesi, Indonesia (van Straaten et al., 2011). As the frond litter also contributes to heterotrophic respiration upon decomposition, we assumed this fraction to be 80% of frond litter biomass C, based on the frond-litter decomposition rate in the same plantation (Iddris et al., 2023). We used the area-weighted value (based on the areal coverages of the three management zones; see 2.1 above) of the annual heterotrophic respiration to calculate NEP for each replicate plot.

Third, the GWP was calculated following Meijide et al. (2020) and Quiñones et al. (2022).

GWP (g CO_2-eq m^{-2} yr^{-1}) = (NEP × 3.67) + (soil N_2O fluxes × 298) + (soil CH_4 fluxes × 25) (6)

whereby 3.67 is C-to-CO_2 conversion, and 298 and 25 are CO_2-equivalents of N_2O and CH_4, respectively, for a 100-year time horizon (IPCC, 2006). Similarly, we used the area-weighted values of the annual soil N_2O and CH_4 fluxes (see 2.2 above) to calculate GWP for each replicate plot. Negative and positive symbols indicate the direction of the flux: (−) for C uptake and (+) for C export or emission from the plantation.

1.9. Figure S2 It is not clear whether you measured more frequently after fertiliser application. Only using monthly measurements you might not have captured the peak emissions after fertilisation adequately and you cannot base statements on one measurement after fertilisation.

Please see the answers to #1.3 above.

1.10. L 265-275 Be careful what you compare your CO2 fluxes with. Some of your referenced studies reported pure soil respiration measured from soil only with infrared gas analyser and proper soil respiration protocols. You are presenting chamber measurements using a different technique and potentially vegetation present in your chambers. So please add a caveat to this part of your discussion.

As we mentioned in 1.6 above, we removed the aboveground vegetation inside the chamber but the roots at soil depths were not disturbed, which contribute to soil CO_2 efflux. Please refer to Malhi et al. (1999) and Trumbore (2006; see Figure below) the definition of soil respiration = autotrophic + heterotrophic respiration.

1.11. L331 If you have only measured once after fertilisation, your entire argument might be flawed

Please see the answers to reviewer 1's question #1.3 above.

1.12. L 337 change to 'reduced'

Thank you for pointing this out. We changed this.

1.13. L429 You only measured GHG for one year so concluding here over 4 years is a bit misleading, if you are including results from other studies in this statement please mention it.

Thank you for pointing this out. What we meant is the first four years of this oil palm management experiment. Of course the soil GHG fluxes were measured only during 2.5-3.5 years of the experiment whereas the palm yields and biomass were measured since the start of this experiment through 2020 (covered in this study) until now (beyond this manuscript's study period).

To avoid confusion, we changed the sentence to:

"During the 3-4 years of this management experiment, soil GHG fluxes, GWP, and yield in reduced fertilization with mechanical weeding remained similar to conventional fertilization with herbicide application, signifying the strong legacy effect of over a decade of high fertilization regime prior to the start of our experiment in this mature oil palm plantation."

References

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