

Reviewer 1

In regions that take climate change mitigation seriously, research on ecosystem carbon cycling and greenhouse gas GHG emissions is of high relevance, with soils, particularly nutrient-rich soils with high carbon content, being one of the key focuses for nature based climate stakeholders. By investigating soil GHG emissions, this paper contributes to filling existing knowledge gaps on this matter. The study is particularly relevant by addressing less studied drivers of soil emissions, specifically the impact of feral pigs, thereby providing insight into a less explored aspect of ecosystem functioning. The results offer valuable empirical evidence demonstrating that feral pigs significantly affect soil conditions and GHG emissions, drawing attention to an important issue.

The introduction of the paper successfully and concisely establishes the topicality of the study, provides useful context on the role of invasive ungulates such as feral pigs in tropical Australian ecosystems, and very briefly introduces current understanding of their impacts on GHG emissions. However, the overview of existing knowledge on soil GHG emissions appears somewhat disproportionate and could be slightly expanded.

The amount of sampled data is not explicitly stated and appears relatively limited compared to typical soil GHG emission studies. Nevertheless, this limitation is justified by the specific study conditions, including the remoteness of the area and its inaccessibility or safety constraints during large parts of the year. These constraints do not detract from the overall quality of the study or manuscript. The paired study design, with parallel measurements at disturbed and relatively undisturbed sites, is appropriate and allows for a meaningful assessment of disturbance effects.

The results are sufficient to support the interpretations and conclusions, and the applied methods are generally valid. However, transparency of the Methods section should be improved, particularly by providing more detailed explanations of underlying assumptions, site conditions, and technical aspects of data collection and processing. This would enhance traceability and reproducibility.

Overall, the study is well presented, clearly structured, and written in fluent language. The title accurately reflects the content of the paper.

Specific comments

25: The abstract states that animals significantly affect the “carbon cycle”; however, the information presented in the abstract and results indicate that impacts extend beyond the carbon cycle to greenhouse gas emissions more broadly. This could be specified more precisely.

True, we have changed the term “carbon cycle” to “greenhouse gas fluxes”

L24: “This study provides another compelling example of how animal populations can significantly impact greenhouse gas fluxes at the landscape scale”

L313: “..they also increase soil CO₂, CH₄, and N₂O emissions, confirming that feral pigs pose a serious threat to soil carbon and other biogeochemical cycles (O’Bryan et al., 2021).”

30: “climate change and human impacts”, climate change is attributable to human activities; the wording can be adjusted accordingly.

Agree, we have added “other human impacts” to clarify that climate change is a human impact:

L28: "As climate change and other human impacts on landscapes intensify, multiple approaches are needed to decrease greenhouse gas emissions"

30: *"one such solution is the restoration", while restoration is strongly promoted as a climate mitigation measure, empirical evidence remains equivocal, particularly when accounting for spatial and temporal dimensions of uncertainties. The sentence can be adjusted accordingly.*

We have added the adjective "potential" to acknowledge the uncertainty:

L31: "One potential solution is the restoration and improved management of wetlands."

33: *"These potent greenhouse gases are emitted in large quantities in wetlands from tropical climates", this is observed in all climates and can be adjusted accordingly.*

We have removed the term "tropical climates"

L33: "These potent greenhouse gases are emitted in large quantities in wetlands, mostly when they are polluted (Rosentreter et al., 2021; Saunio et al., 2020)"

75: *"increase in soil decomposition", the implied linkage between decreasing oxygen availability and increased soil decomposition appears counterintuitive. The sentence may be split into separate sentences addressing different gases for clarity, if necessary.*

Good point- we have rewritten the predictions as follows:

L69: "We predict that nitrogen inputs will increase due to animal excretion (Krull et al., 2013), and that soil oxygen (and thus its reduction-potential or redox) will decrease due to the removal of vegetation and increased microbial activity (Doupé et al., 2009; Liu et al., 2020). We expect these changes to result in increased soil CH₄ emissions and incomplete nitrification-denitrification, which increases N₂O emissions (Anderson & Levine, 1986)."

120: *The soil horizon or sampling depth (cm) used for soil sample collection should be specified.*

We have clarified that the soil measurements and soil samples were taken from the surface:

L120: "At each plot, surface reduction-oxidation potential (redox; 3-5 measurements) and soil temperature were determined with a redox meter (HQ 11d ORP- meter, Hach, calibrated against ZoBell's Solution)."

L123: "Three surface (0- 5 cm) soil samples of a known volume were taken at each plot, weighed, and oven-dried at 50°C"

135: *The equation 1 appears to be derived from the ideal gas law; therefore, the temperature used should correspond to the chamber headspace (gas) temperature rather than soil temperature. If headspace temperature was not measured, please state this explicitly and discuss the potential*

uncertainty associated with using soil temperature as a proxy. Soil depth for temperature measurements is not specified.

We have recalculated all the emissions using the air temperature instead. Differences were $\leq 5\%$ of the previous calculations. We have clarified as follows:

L120: "At each plot, surface reduction-oxidation potential (redox; 3-5 measurements) and soil temperature were determined with a redox meter (HQ 11d ORP- meter, Hach, calibrated against ZoBell's Solution)."

L150: "Fluxes (F) were calculated per hour from the net changes in gas concentrations (N, mol) during the incubation time (t, hours), per volume of the chamber (V, m³), at a given air temperature (T, °K), assuming a pressure of one atmosphere"

145-150: Section 2.4. Root sampling depth is not specified. In disturbed plots, measured root-derived emissions likely reflect decomposition processes rather than active respiration. A more accurate approach would therefore be to define these emissions as decomposition rather than respiration. In addition, it is unclear how roots (both dead and living) collected at the reference plots were interpreted in the analysis, whether all measured emissions were assumed to represent decomposition and comparable with estimates from disturbed plots. Furthermore, as soil flux measurements were also conducted at reference sites with undisturbed, vegetated soil, it remains unclear how aboveground autotrophic respiration was treated in the study.

155: "Fluxes of CO₂ were also included by correcting for respiration using the differences in emissions (%) from vegetated and unvegetated plots". The purpose of this data manipulation remains unclear at this point in the manuscript. Clarification is required regarding which fluxes were corrected and whether the correction was applied to the reference plots to account for the presence of living biomass. It is not straightforward to correct part of the dataset by calculating differences between two datasets that are not directly comparable. Specifically, disturbed plots include fluxes from soil organic matter decomposition and decomposition of remaining dead root biomass, whereas reference plots include soil organic matter decomposition, decomposition of roots from natural mortality, respiration of living roots, and respiration of aboveground vegetation. Hence, the purpose of the correction is not clear. Further clarification is therefore needed as to why a simple difference between reference and disturbed plots was not used, and, if root respiration and/or root decomposition emissions were measured, why these data were not applied in the correction.

At line 265, it becomes clear that the correction was applied to exclude root emissions; however, the correction procedure should be explained more clearly earlier in the manuscript (section 2.5).

We have changed the term "soil respiration" to either "root respiration" or "soil decomposition". We have also included the details of the correction earlier in the Methods, as well as the caveats of this calculation:

L159: "Soil CO₂ fluxes are a combination of the decomposition of organic matter and dead roots and the respiration of live roots, the latter contributing up to 79% of the total (Krauss et al. 2012). To test the contribution of root respiration to soil CO₂ emissions, we compared CO₂ emissions from the unvegetated and vegetated plots measured during the Kunumleg season. Additionally, we measured root biomass at each reference and disturbed plot by sampling the surface (top 10cm) with a mini core (7.3 cm diameter)."

L159: “We acknowledge the limitations of this approach, as root respiration was measured once roots were extracted from the soil, without accounting for the effects of the aboveground vegetation and the soil profile vegetation, which could consume CO₂ through photosynthesis and other non-photosynthetic pathways (Rodriguez et al 2025). Furthermore, direct root respiration cannot be distinguished with certainty from organic matter decomposition without the use of additional tracers, such as ¹⁴C (Trumbore et al 2006). Thus, our estimations on root respiration contributions to CO₂ emissions should be interpreted as a first-step calculation.”

155: The manuscript notes that instantaneous fluxes are extrapolated to annual fluxes per hectare; however, the study design does not allow for accurate annual extrapolation. This should therefore be avoided, or the formulation should be reframed to clearly indicate that the reported values represent instantaneous fluxes expressed in units of t ha⁻¹ yr⁻¹, with explicit clarification of whether these were obtained by averaging the measurements. An alternative approach could be to present relative reductions in emissions without implying that these can be extrapolated to annual values.

We have removed the annual extrapolations from the results and are now presenting only hourly rates. Following the Reviewer 2 request, we provide a broad calculation in the Discussion of potential annual reductions based on our results and supported by published data.

L366: “We cautiously estimate annual emissions from pig disturbance using our data, supplemented by published estimates of emissions during flooding (Bass et al. 2014). We consider emissions from flooded Melaleuca swamps to be representative of reference sites and open-water areas without vegetation to represent sites damaged by pigs. Seasonal differences were included in our estimations, considering that the wet seasons Kudjewk and Bangkerrent seasons span from 20 Dec-30 April, the cool seasons, Yekke and Wurrkeng, from 1st May- 15th August (data from this study), and the hot dry seasons, Kurrung and Kunumeleng seasons, span from 16th Aug to 19th December (data from this study). We estimate that annual emission reductions by comparison (reference vs disturbed) are 13.2 Mg CO₂ ha⁻¹ yr⁻¹, 1.1 Mg CH₄ ha⁻¹ yr⁻¹, and 0.004 Mg N₂O ha⁻¹ yr⁻¹, equivalent to reductions of 43.4 Mg CO_{2-eq} ha⁻¹ yr⁻¹. We can then extrapolated these emissions to the Kakadu and adjacent river floodplains (See Fig 1; 356,800 ha, Ward et al. 2014) considering that about 10% of the area is disturbed by pigs (unpublished data). We estimate emissions of 0.47, 1.04, and 0.04 Mt CO_{2-eq} yr⁻¹ for CO₂, CH₄, and N₂O, respectively, or a total of 1.5 Mt CO_{2-eq} yr⁻¹. These levels of emissions are equivalent to 5.6% of the Northern Territory's emissions in Australia, or 57.4% of the Territory's agricultural emissions. Although we have acknowledged the limitations of our calculations and the challenge of removing the thousands of pigs inhabiting these wetlands, it is clear that there is significant potential to reduce greenhouse gas emissions through feral pig control.”

230-235: It is unclear what exactly is being compared. Please clarify whether all data are aggregated or whether the comparison still retains subgrouping by disturbance.

We have clarified in this legend and in the legend of Figure 4:

L255: “Violins represent the distribution of the average of five chambers of three sites (Djabulukgu, Mamukala, and Munmarlay).”

205; 220;230: CO₂ emissions were lower at reference plots during Yekke (8–14 June 2023) but higher during Kunumleng (25–30 October 2023). In addition, CO₂ emissions during the cooler Yekke period were higher than during the hotter, pre-monsoon Kunumleng period. Can this be explained by seasonal vegetation dynamics? It may be so if by the Kunumleng period, vegetation at reference plots may have developed greater biomass, leading to increased autotrophic respiration and consequently higher CO₂ emissions. If so, this would imply that the observed differences reflect not only soil processes but also seasonal variation in vegetation activity. If this is plausible, adding some information on vegetation dynamics may be valuable. At the same time, can the lower CO₂ emissions observed during Kunumleng, despite higher temperatures, be related to drier soil conditions, which can limit microbial activity and soil respiration (this was confirmed at discussion)? In this case, adding information on meteorological conditions during the study periods would therefore improve the interpretation of the observed CO₂ dynamics.

Thank you for the ideas. The latter (dry soil conditions) may apply to this situation, as the Kunumleng period is very hot and dry, and while the trees remain, understorey vegetation has mostly dried up, and soil humidity decreases. We have added this information, along with some meteorological conditions before sampling, to the Methods and Discussion.

L95: “. Both sampling trips were preceded by dry conditions with no precipitation in the last 30 days and mean daily temperatures ranging from 33-36 °C during sampling in Yekke and 38-40 °C in Kunumeleng (Jabiru Airport Station, 14198, Australian Bureau of Meteorology).”

L325: “During this season, understorey vegetation and litter were scarcer, limiting organic carbon inputs into the soil and potentially causing reduced CO₂ fluxes compared to Yekke.”

260: *It is unclear which study period is represented by soil respiration in Table 4. Unclear why values in the table do not seem to match those represented in Figure 5.*

We have modified this Table, first clarifying that the root respiration measurements were done during the Kunumleg season. We have also removed the soil CO₂ values from this Table to avoid confusion, as these were obtained with a different methodology and were not used for any further calculation in this study.

“Table 4. Root respiration and biomass from the top 10 cm during the Kunumleg in reference and disturbed plots by feral pigs.”

In addition, it is not explained in the methods how measured root emissions (probably “respiration+decomposition” or “decomposition” instead of “respiration” only) are expressed in mg m⁻² hr⁻¹.

We have clarified in the Methods how we converted root respiration to aerial rates.

L160: “To test the contribution of root respiration to soil CO₂ emissions, we compared CO₂ emissions from the unvegetated and vegetated plots measured during the Kunumleg season. Additionally, we measured root biomass at each reference and disturbed plot by sampling the surface (top 10cm) with a mini core (7.3 cm diameter).”

L167: “Root respiration was converted to aerial emissions considering the area of root sampled (22.9 cm²).”

335. *This part of the sentence is confusing: “ although it does not incorporate the potential absorption of CO₂ as it travels from the sediment to the atmosphere.” The hypothesis was not explicitly addressed in the results or discussion.*

We have removed this statement and clarified the limitations of our estimations in the Methods section:

L167: “We acknowledge the limitations of this approach, as root respiration was measured once roots were extracted from the soil, without accounting for the effects of the aboveground vegetation and the soil profile vegetation, which could consume CO₂ through photosynthesis and other non-photosynthetic pathways (Rodriguez et al 2025). Furthermore, direct root respiration cannot be distinguished with certainty from organic matter decomposition without the use of additional tracers, such as ¹⁴C (Trumbore et al 2006). Thus, our estimations on root respiration contributions to CO₂ emissions should be interpreted as a first-step calculation. “

Technical corrections

20: N₂O typo

135-140: multiple typos, format as superscript where necessary. Use of terms “plots” and “sites” can be harmonised through the manuscript.

We have fixed the typos with adequate subscripts or superscripts and harmonized the terms “plots” and “sites”.