Response to reviewers' comments:

Reviewer #RC3 (Remarks to the Author):

In this manuscript, authors applied an opaque chamber to measure fluxes of three major greenhouse gases (GHGs) within an urban park in 2023. Authors also developed a random forest model to 1) explore the relative importance of different environmental factors to GHG fluxes and 2) map the hot/cold spots of GHGs over the whole park. The dataset collected in this study is unique and most of the presentation is scientifically valid. Authors highlighted their findings in urban ecosystems, but discussion on how different their findings compared to natural ecosystems is missing. This manuscript shall be improved to add more discussion that addresses this issue.

1. Line 19: Calculation of CV is based on weekly/monthly/annual mean fluxes?

Response: Thank you for the comment. To assess spatial variability, the coefficient of variation (CV) was calculated using cumulative GHG fluxes for individual sampling sites across over the vegetation-growing and frost-free period. Regarding temporal variability, the CVs were calculated using daily mean GHG fluxes. For clarity, we have incorporated these descriptions in the revised manuscript.

2. Line 72: What is the total area of the park?

Response: The total area of Aarhus University Park is about 8.2 hectares. This information has been added to the manuscript:

3. Line 100: "During the vegetation and frost-free period" what does "vegetation" mean here?

Response: In this study, the 'vegetation and frost-free period' was defined as the period when the daily mean air temperature was consistently above 0 °C. Thus, here 'vegetation' means 'vegetation-growing'. For clarity, we have corrected 'vegetation and frost-free period' to 'vegetation-growing and frost-free period' throughout the whole manuscript.

4. Line 110: "chamber area" is ambiguous. Shall be clarified. How about "the area of the chamber top face"?

Response: Thank you for the suggestion. We have revised it for clarity.

5. Line 131: "In this study, the observed GHG fluxes were classified into three categories" shall be "In this study, the different subsections of park were classified into three categories based on the relative magnitude of observed GHG fluxes"

Response: Thanks. We replaced the original sentence with the recommended description.

6. Line 137: "M is the median and Q3 – Q1 is the interquartile range of the measured fluxes". Please clarify the temporal resolution of measured fluxes used for calculating M, Q3 and Q1? Instantaneous value, weekly mean or something else?

Response: Thank you for the comment. In this study, the median (M) and interquartile range (Q3–Q1) were calculated based on daily GHG fluxes from individual sampling sites during the vegetation and frost-free period. We added this information in the revised manuscript for clarity.

7. Line 144: Need to rephrase this paragraph. I suggest to revise as follow but also expect authors to double check and make sure that the revised text has identical meaning: "First, the counts of hot, cold,

and normal spots varied substantially across the three gases, with the normal spots category being predominant. This imbalance could potentially introduce biased sample numbers of training data under different categories, thus causing the RF model favoring the majority class and failing to accurately identify the minority classes. To address this issue, the minority categories were oversampled during training. We used an ad hoc, iterative approach to identify the most effective inflation factor of oversampling for each GHG (Tables S1-S3).

Response: Thank you very much for editing. We replaced the original sentence with the recommended description.

8. Line 154: In Table S5. There are three numbers in each row. What do they mean respectively?

Response: The different numbers for each hyperparameter correspond to the different combinations of hyperparameters we used over a grid search. That is, for the combination between each individual number, we have run the RF model and derived the performance metrics. The best performing model was selected as the final model. To improve clarity, we have added a detailed explanation of the hyperparameter values and their role in the grid search procedure to the caption of Table S5.

9. Fig. 2: Authors need to improve this figure through resolving the following issues: 1) Layout is too tight, 2) precipitation and soil moisture shall use the same y axis scale, 3) air and soil temperature shall use the same y axis scale, 4) x axis labels are too crowd, consider reducing, e.g., can put 1 label for each month, 5) y axis scale (GHG fluxes) can be changed to logarithmic scale, 6) subplot id (a-e) can be moved inside the upper left corner of subplots and 7) too much gridlines inside the plot, but this can be improved after reducing x axis label and change y axis to logarithmic scale.

Response: Thank you very much for the comment and suggestion. To improve visual clarity and readability, we have split the original Figure 2 into two separate figures (now labeled Figures 2 and 3), please see them below:

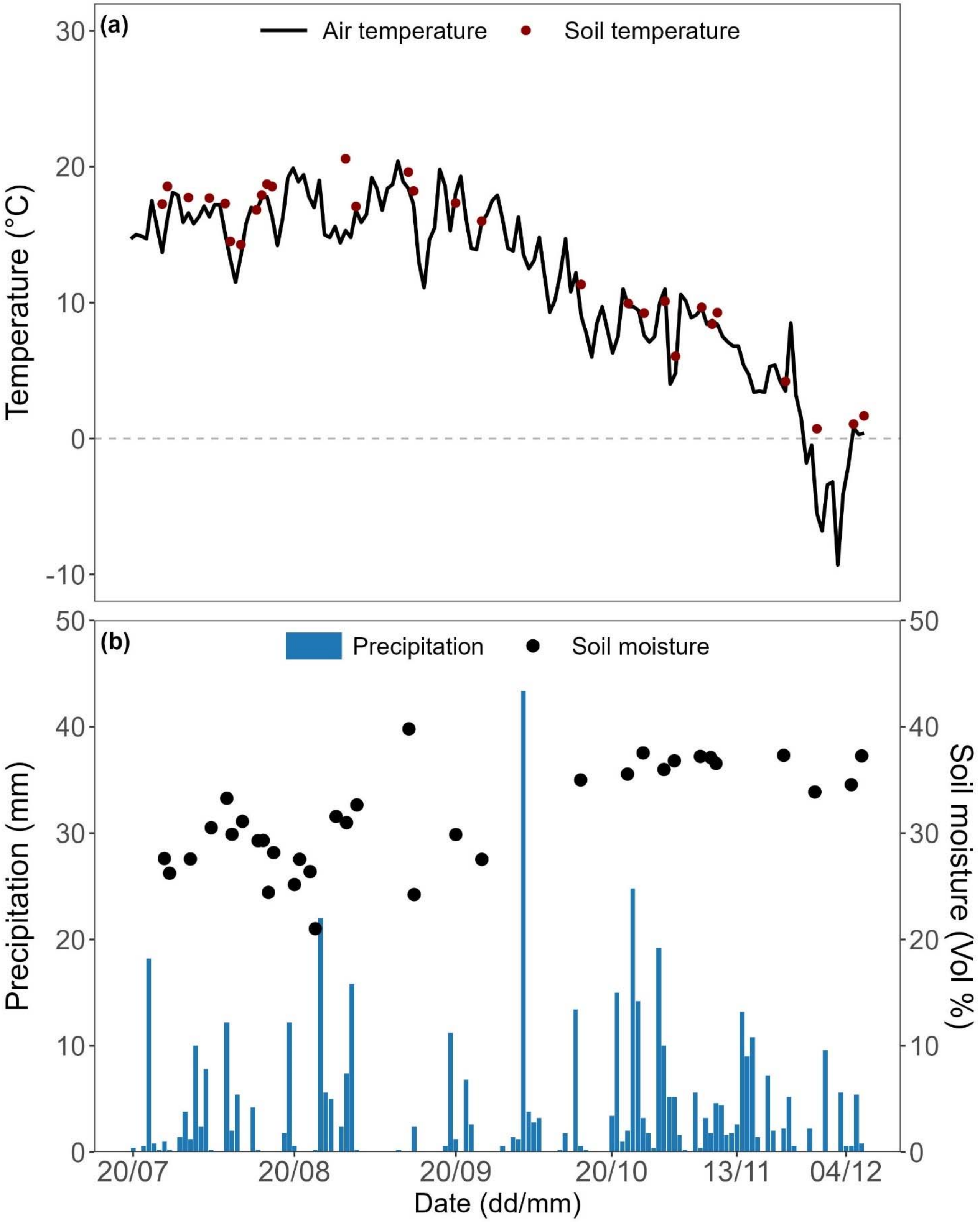

Figure 2: Seasonal variations in daily mean air (source Danish Meteorological Institute, 2025) and soil (5 cm) temperature (a) and daily precipitation (source Danish Meteorological Institute, 2025) and mean volumetric soil (0-5 cm) moisture content (b) over the entire observation period from July to December, 2023.

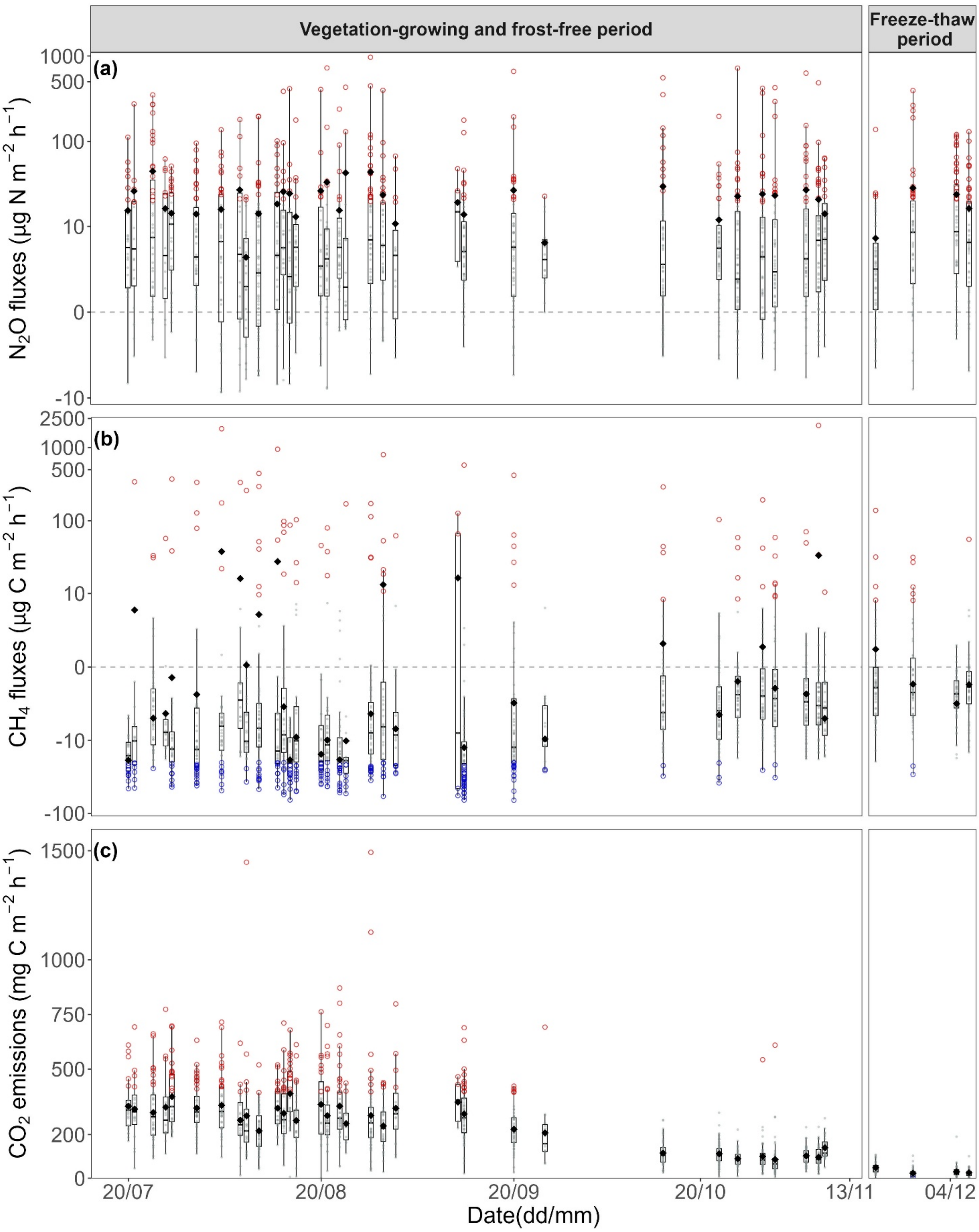

Figure 3: Fluxes of soil nitrous oxide (N_2O) (a), methane (CH_4) (b) and ecosystem (i.e. soil and plant) respiration (CO_2) (c) over the entire observation period from July to December, 2023.The vegetation-growing and frost-free period spans from 20 July to 21 November, 2023, while the freeze-thaw period spans from 22 November to 31 December, 2023. In panels a-c, the black solid diamonds and lines

inside the box represent the mean and median value, respectively. The box borders represent the 75th and 25th percentiles, and the whisker caps represent the 95th and 5th percentiles. The red and blue circle points represent hot spots and cold spots, respectively, and grey circle points represent neither hot spots nor cold spots of observation data. The definition of hot and cold spots can be found in the Materials and Methods section. To improve visualization across the wide range of flux values, the y-axes are displayed using a pseudo-logarithmic scale; this transformation was applied only to the y-axis for visual clarity and does not affect the original data values or statistical interpretation.

10. Line 192: "recorded during both the vegetation and frost-free periods and the freeze-thaw period." Any snow cover during the freeze-thaw period? Please clarify.

Response: Yes, there was snow cover during the freeze–thaw period. According to data from the Danish Meteorological Institute (http://www.dmi.dk), the snow cover depth during this period ranged from approximately 0.1 to 13.1 cm. For clarity, we added this information to the revised manuscript.

11. Line 216: I'm a bit surprised that total N content is not one of the top predictors for N_2O flux. Please explain the reason.

Response: Thank you for the comment. Total N content was not significant, and, was not used as one of the key factors controlling N_2O fluxes, we found that SOC was the key factor in predicting N_2O fluxes, which may also indicate the relative magnitude of microbial substrate availability.

12. Line 231: "Areas draining toward the artificial ponds showed the highest overall probability of becoming cold spots of CH_4 uptake over time" It's not likely that regions closer to ponds have stronger CH_4 uptake. Not sure if this finding is only indicated from RF model prediction, or reflected by the collected original samples. Since VWC is the major predictors of CH_4 flux, I suggest authors add every sample as dot to the map, with different colors showing either hot or cold spots, and plot VWC anomaly (actual VWC - mean) as basemap to support your finding.

Response: Thank you for this helpful comment. As we mentioned in our response to reviewers #RC1 and #RC2, we added the Supplementary Figure S5, which shows the frequency of observed hot and cold spot fluxes. As Figure S5 shows, our observations also revealed that the sampling sites near the artificial ponds sometimes functioned as sources of atmospheric CH4, while at other times, they exhibited high CH4 uptake. This variability is likely due to the fact that the magnitude of CH_4 fluxes is mediated by multiple factors such as soil moisture, bulk density, total N content and soil organic C as well as C/N ratio.

13. Fig. 4 & 5: Both figures show correlations between specific environmental predictors and GHG fluxes, so I suggest merging them together. Also, please put CO_2, CH_4 emission, CH_4 uptake and N_2O subplots in different rows for clarity purposes.

Response: Thank you very much for the suggestion. For the Figure 4, we mainly focus on the environmental factors controlling the spatial variability of GHG (N_2O, CH_4 and CO_2) fluxes. With regard to Figure 5, we tried to show the specific environmental factors in shaping temporal patterns of GHG fluxes. To show the differentiation, we separated these two figures. Nevertheless, according to the comment, we have harmonized the color scheme across Figures 4 and 5 for improving clarity and readability, i.e. using the same colors for the same dependent variables (i.e. N_2O, CH_4 and CO_2 fluxes). Please see the figures below:

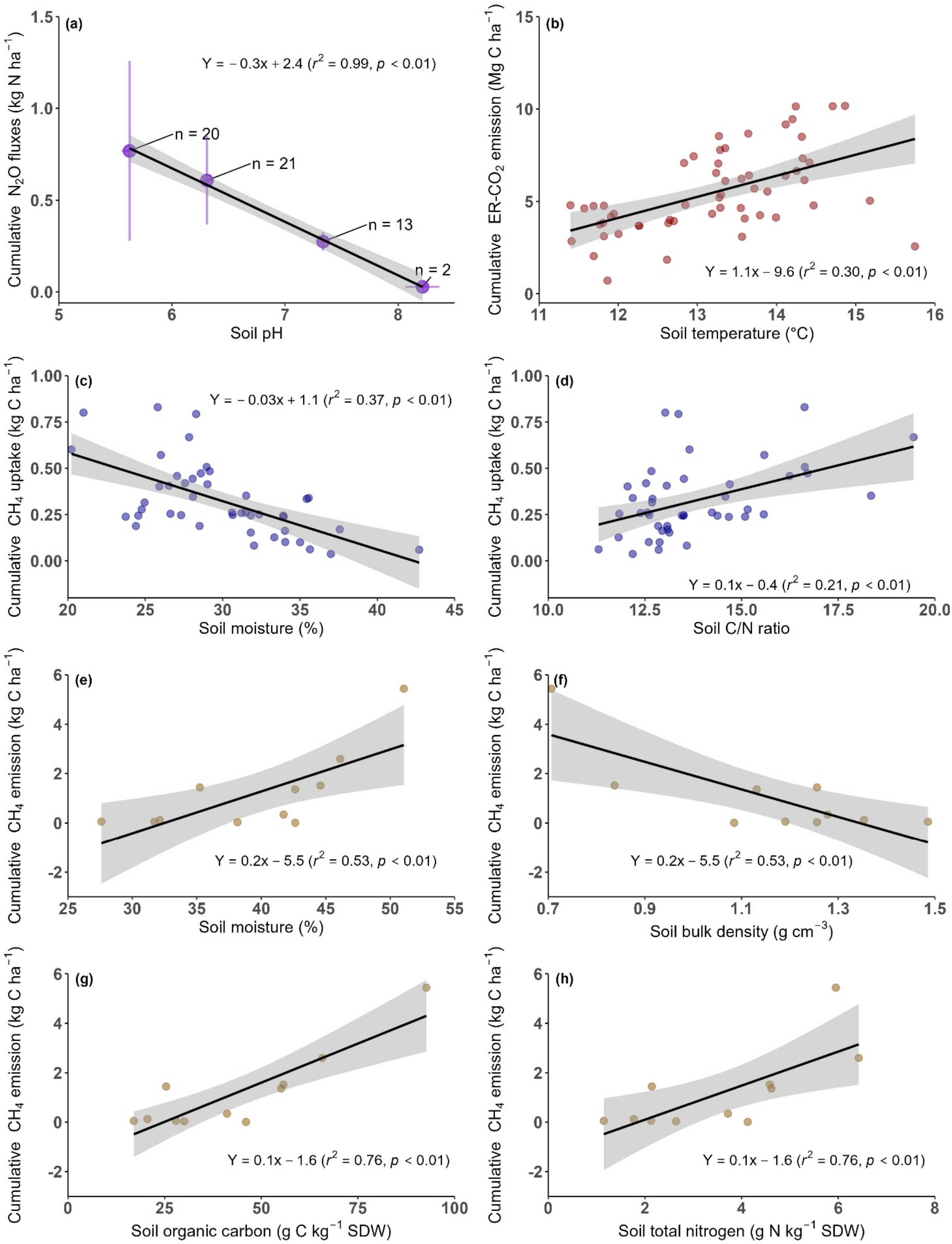

Figure 4: The relationships between cumulative nitrous oxide (N_2O) fluxes and soil pH (a), between cumulative ecosystem respiration (ER-CO_2) emissions and soil temperature (b), between cumulative

methane (CH_4) uptake (expressed as absolute values) and soil moisture (c) and soil C/N ratio (d), between cumulative CH_4 emissions and soil moisture (e), soil bulk density (f), soil organic carbon (g), and soil total nitrogen (h) across all the sampling sites. In panel a, soil pH was binned at a step width of 1 (i.e. 5.0-6.0, 6.0-7.0, 7.0-8.0 and >8.0), and points are given as mean values ± standard error, with numbers referring to the number of observations. SDW: soil dry weight. The shaded area of each panel represents the 95% confidence band.

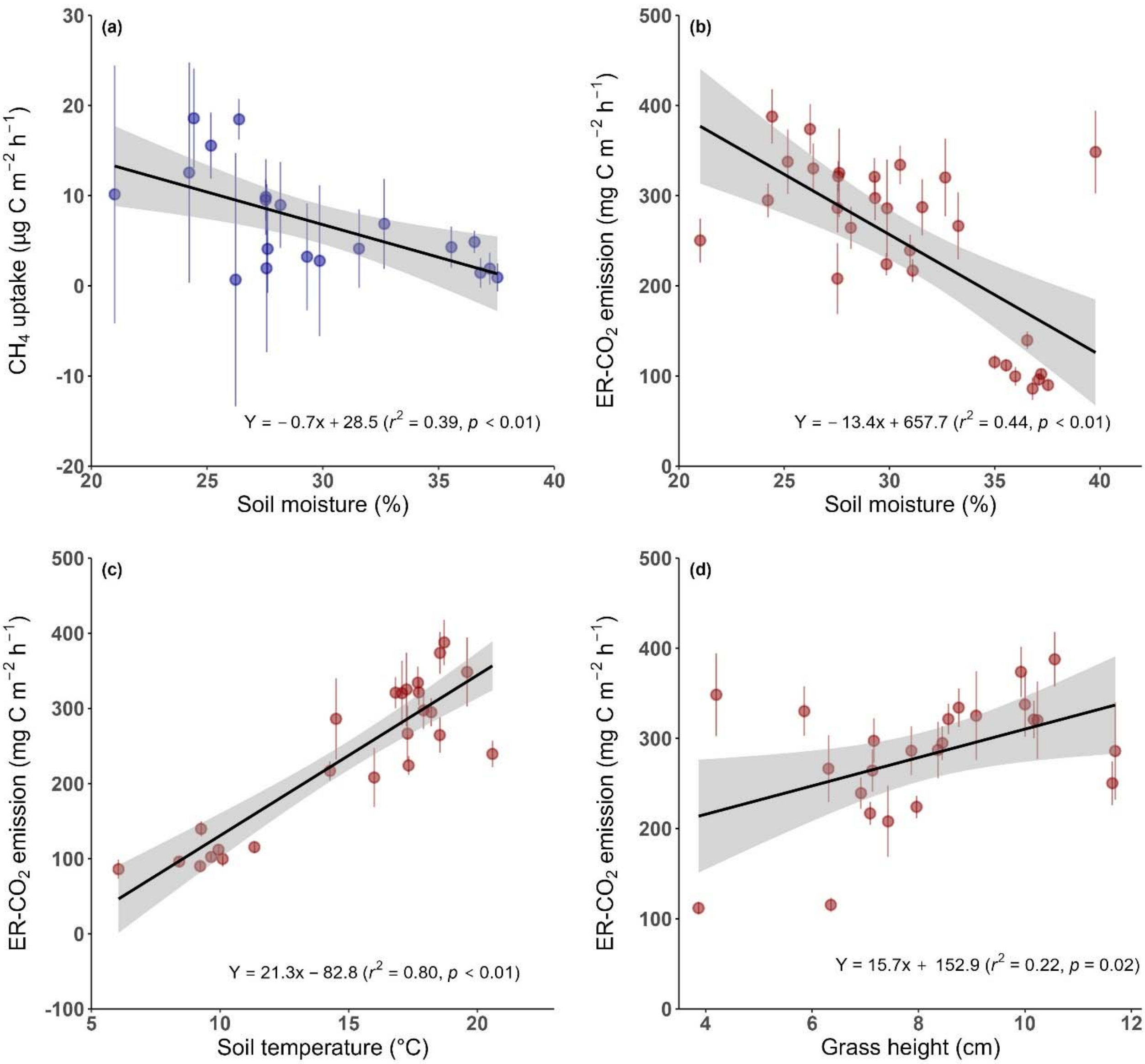

Figure 5: The relationships between methane (CH_4) uptake (expressed as absolute values) and soil moisture (b), between ecosystem respiration (ER-CO_2) emissions and soil moisture (b), soil temperature (c) and grass height (d) across the vegetation-growing and frost-free periods. Points are given as mean values ± standard error across all the sampling sites at the same measurement time. The shaded area of each panel represents the 95% confidence band.

14. Line 363: "Moreover, the SOC decomposition process is constrained by anoxia, which restricts the release of nutrients necessary for CO_2 formation (Keiluweit et al., 2017)." If anoxia is important, I would suggest authors explore the correlation between water-filled pore space (WFPS) and CH_4 fluxes to corroborate your finding.

Response: Thank you for the suggestion. Regression analysis revealed a positive correlation between CH4 fluxes soil water-filled pore space (WFPS) (see the figure below). This supports the presumption that the anoxia under high soil moisture conditions stimulates CH4 emissions, while inhibiting aerobic CH_4 uptake and CO_2 emissions. We added this figure and the associated discussion to the revised manuscript.

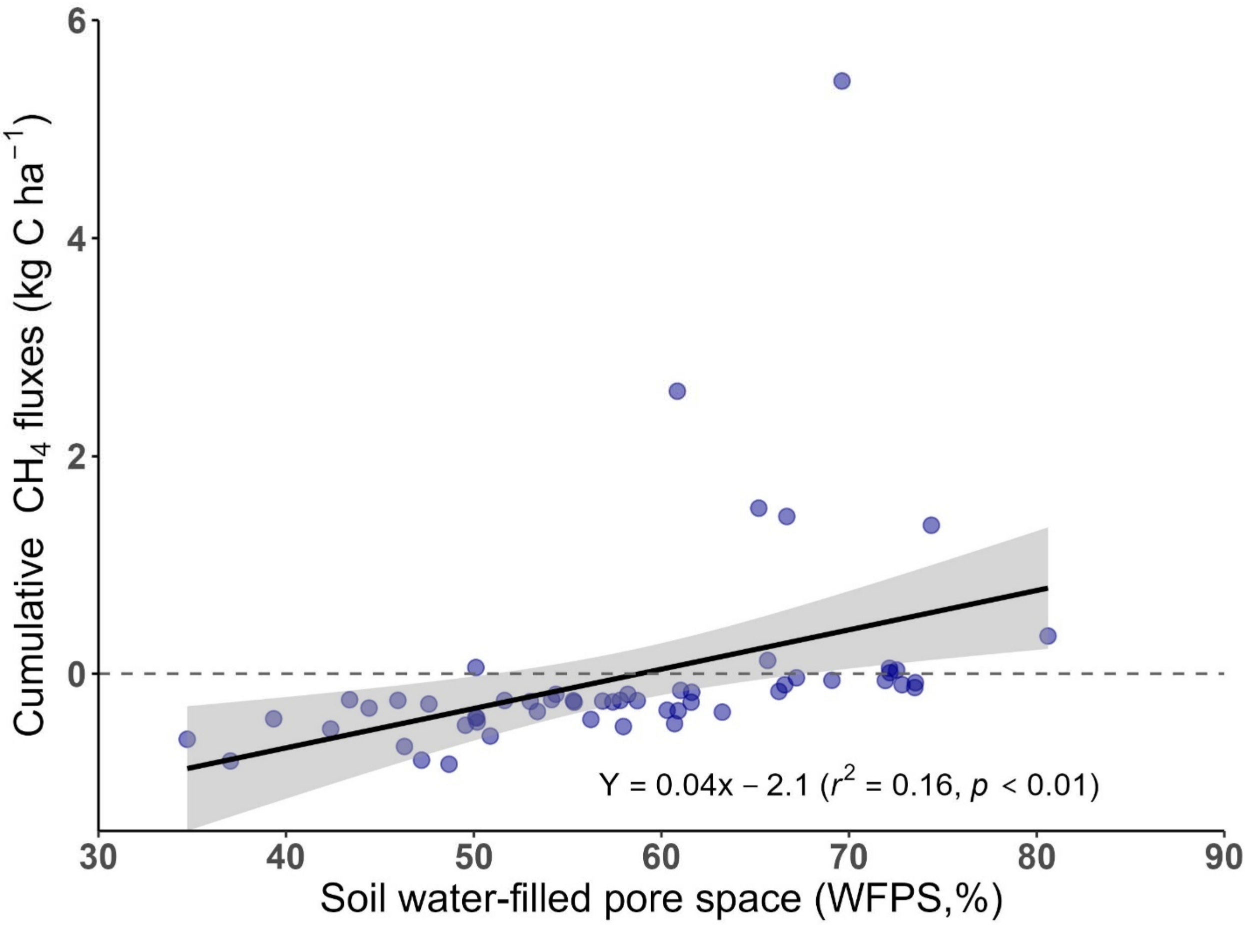

Figure S6: The relationships between cumulative methane (CH_4) fluxes and soil water-filled pore space across all the sampling sites. The shaded area represents the 95% confidence band.

15. In the discussion section, it is important to add a comparison between this study, which measured GHG fluxes over urban ecosystem, and other studies measuring the same fluxes from natural grassland, since it is one of the highlights of this work.

Response: Thank you very much for your suggestion. We added the discussion comparing the observed fluxes from urban greenspaces to those of natural grassland and forest ecosystems, which indeed improves the quality of this section.