Author response to reviewer comments on “Plant belowground traits indicate increased plant-mediated methane transport along a peatland permafrost thaw gradient” by Määttä et al.

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We thank the editor for the feedback. We have addressed the reviewer comments and modified the manuscript accordingly. Based on the reviewer comments, the major changes included rerunning the analyses with CH_4 flux data that has been updated for the QA/QC steps (this did not change the main findings of the manuscript), added peat moisture data as an additional environmental variable, and combined and polished some figures to improve their readability. We have also modified the text to improve its readability and refined some Appendix tables for their decimals (Tables C1, C2, and C4). We think the reviewer feedback improved the manuscript and are happy to send you the revised version.

Please find our responses to each reviewer comment below in bold.

Response to comments by Reviewer 1

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Controls (or drivers) of the exchange of methane between the atmosphere and the surface of various wetlands have always been complicated, because of the nature of the processes and pathways and the large spatial variability across short distances, combined with temporal variability. Initially, simple variables such as temperature, water table and plant functional type were useful in ‘explaining’ patterns of methane exchange across landscapes. Since then, attention has been given to a variety of properties and processes which have led to a better ‘explanation’ and perhaps ‘prediction’ of the methane exchange. For belowground activities, important processes are provision of carbon for methanogenesis and the ability of plants to transport methane directly (avoiding methanotrophy in the profile) as well allowing oxygen to create a potential zone of methanotrophy in the rhizosphere. Thus, linking belowground root/rhizome traits and methane emission can be ‘complicated’ but a necessary advance. This manuscript is an example of the latter, focusing on the role of root and rhizome traits in the exchange (emission) of methane, based along a gradient created by the thawing of permafrost palsa in northern Sweden. Three ‘thaw stages’ have been recognized at this site, with changes in thermal regime, hydrology and vegetation characteristics creating a very large variation in methane emission rates. The research focuses on determining root and rhizome traits across triplicates of each thaw phase, though this is not done in the automatic flux chambers, but from sites located nearby with similar properties. As noted by the authors, there is not complete species similarity in mean coverage between the triplicate chamber and core data but when combined into herbaceous and shrub categories there is general agreement (Table 1). Daily median flux of methane was calculated, to avoid the usual ‘burp’ of methane occurring occasionally which would be unlikely to be derived from root processes, and chamber carbon dioxide flux was used to define seasonal patterns. Root and rhizome data were collected carefully from depth increments and biogeochemical data were used to provide evidence for some of the processes leading to methane production, and how they might be related to root activity.

The manuscript is well structured and written and provides valuable evidence for the role of belowground plant activities in controlling methane emissions. It is ‘digestible’ in that the information in the manuscript is restricted to two Tables and five Figures, with voluminous supporting data in Appendices. The strong Introduction ends with several expectations/hypotheses based on previous studies, but in this case applied to the specific Stordalen site, in which palsa are thawing and thus perhaps similar to features elsewhere in the Arctic. Based on methane fluxes from the nine chambers and root characteristics from the ‘similar’ sites, the study presents strong evidence for correlations between methane emission rate and the herbaceous and shrub root and rhizome properties, and whether patterns changed with the season, based on carbon dioxide exchange. In general, it appears that correlations were stronger for root properties compared to rhizomes, though there are mixed relationships shown in Figures 3 and 4. The reasons for positive, negative or no correlations were examined in the Discussion and the relevance of these relationships may vary with the specific features of Stordalen, which are somewhat unusual. The relationships between the traits and methane emission were examined in terms of processes related to changes from shrubs to herbaceous plants and the root trait structure (e.g. density, specific length and diameter), and drew upon results presented elsewhere which could be applicable at Stordalen.

The overall conclusion was that belowground root/rhizome activities were an important component of methane emission, that change from shrubs to herbaceous would lead to increased emissions, but there is a bit of ‘ying-yang’: shrubs may supply more carbon substrates, whereas herbaceous plants may be important conduits of methane to the atmosphere. Such is life in the real world of Nature and ‘teams’ like these authors are needed to see at least part of the whole.

Thank you, Dr. Moore, for your comprehensive analysis and positive evaluation of our manuscript.

The study is ‘well referenced’, with 145 in the References, perhaps too many?
We agree, and have now removed 19 references from the manuscript. However, the number of references remains rather high because we think it is valuable to cite the many studies looking at CH_4 cycling at Stordalen, and to

also comprehensively discuss the root and rhizome traits with references to root (and rhizome) ecological literature.

Specific comments:

In Table 1, it seems that mosses formed a significant plant cover in the chambers (e.g. Sphagnum balticum, capillifolium and riparium in the three thaw stages). Would methane emission rates be affected by this coverage and some differences between chambers and cores and different wetness? This is addressed in 4.2 line 486 onwards …..

This is true, and we have added these points to the sentence as follows (and removed one reference as per previous comment):

"In addition, *Sphagnum* spp. can host methanotrophic CH_4-consuming bacteria (e.g., Larmola et al., 2010; Putkinen et al., 2014), which may have increased CH_4 consumption in the more O_2-rich intact and partly thawed stages dominated by *S. balticum* and *S. capillifolium*, with intact stage chambers possibly having higher CH_4 consumption rates than peat cores with no S. balticum (Table 1). However, the average $\delta^{13}CH_4$ emitted from the partly thawed chamber plots was -79.6 ± 0.9 ‰ in 2011, similar to or ^{13}C-depleted relative to the porewater CH_4 at the same sites, indicating little CH_4 oxidation (McCalley et al., 2014)."

A tremendous amount of work went into this study, particularly in the measurements of root and rhizome properties collected from the cores. If I understand correctly, a 12 cm diameter peat core was dived into 10 cm depth increments and these were then divided into four vertical quarters, which was used for trait measurements, resulting in subsampling of the core sections (and subsampling of that in some cases). This are measurements based on an initial volume of 1130 cm3, and it must take considerable time and patience to extract roots and rhizomes, weighing in some cases to 0.00001 g. pH in 0.01M Cacl2 is much easier and quicker …….

This is correct. Picking roots (especially shrub roots) from peat is very time-consuming, and we appreciate the Reviewer's acknowledgement of this hard work.

While I accept that the belowground contribution is important to processes such as methane emission, are there any ways of making it 'easier' to define and measure these properties over a wider range of sites? If so the properties could be included and tested within models which are grappling with the high spatial and temporal variability of methane emission rates.

There are some methods that might make measuring some root (and maybe rhizome) traits a bit easier for a wider range of sites. These include for example minirhizotrons which can help with calculating root length and its changes with time. We mention minirhizotrons in the discussion (4.3) as a possible method for looking into the temporal dynamics of root-mediated CH_4 cycling in Stordalen in the future. However, minirhizotrons also come with

considerable image analysis burden that has not fully been automated yet. Furthermore, root tissue density, porosity and specific root length can only be measured manually by first conducting the time-consuming root picking from samples and then measuring the volume, length and dry mass. X-ray computed tomography may be another way to do higher throughput measurements of roots from intact soil cores. However, we are hard pressed to find literature that has conducted and validated these methods for roots. Perhaps the most promising approach has been developed by Strakova et al. (2020) (https://doi.org/10.3389/fpls.2020.00597) using FTIR spectroscopy to quantify roots in peatlands. As the focus of this manuscript is not necessarily to test different root trait measurement methods, and we already have too many references, we think additional review and discussion of the different root trait measurement methods might not be needed here.

Technical issues:
I found few. I thought that the first two sentences of 2.6 (lines 214-215) could be combined into one: they are repetitive. Minor typos in places.
We have now removed the repeated sentence ("Briefly, CH_4 flux was measured at each permafrost thaw stage with automated chambers.")

Fig. B13. I was confused the right hand diagram. I think the dashed lines have circles whereas the solid lines have triangles …… not what is written in the legend?
Good catch- this was an accident. As Reviewer 2 also suggested, we have improved this figure by separating the 13C-CH_4 and α_C data into their own plots. In the new plots, we do not use the dashed lines and avoid this confusion.

I did find that the total root length of shrubs in the intact sites was about 180 km per square meter (to 30 cm depth). Jeez, as it is 10 km from Stordalen to Abisko, it means that one square meter of intact permafrost has enough shrub root to go back and forth 18 times or perhaps all the way to Norway or the Norwegian Sea? Might get the attention of readers that permafrost is not 'dead' but rich in roots and though root length decreases in thawed sites, the impact of roots and rhizomes and change from shrub to herbaceous plants allows for larger methane emission rates.
Exactly- this is a remarkable finding and highlights the importance of measuring roots also in permafrost peatlands. We have now added an additional sentence highlighting this in the results section (3.1):
"Total shrub root length reached a very high mean of 178.62 km m^{-2} and a maximum of 199.7 km m^{-2} in the intact stage, substantially higher values than for herbaceous roots (mean: 19.79 km m^{-2} and max 33.33 km m^{-2} in the partly thawed stage) (Fig. B4)."
And in the discussion (4.1):
"Following vegetation community shifts, most belowground shrub biomass and total length were found in the intact stage…" and

“In general, these findings, and particularly the remarkably high total shrub root length values, showed that permafrost-affected peat soils are rich in plant roots and likely contribute to the carbon cycling of these ecosystems (Bardgett et al., 2014; Iversen et al., 2015).”

Added new reference:
Bardgett, R. D., Mommer, L., and De Vries, F. T.: Going underground: root traits as drivers of ecosystem processes, Trends in Ecology & Evolution, 29, 692–699, https://doi.org/10.1016/j.tree.2014.10.006, 2014

Response to comments by Reviewer 2

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This study is an exploratory in situ experiment in finding soil biomass trades that can explain CH4 emission. Specifically, these biomass trades are linked to plant-mediated transport of CH4 in different thawing stages in a permafrost peatland in north Sweden.
The topic of this study is relevant and needed to get a better understanding in the processes behind measured CH4 fluxes, which is relevant for upscaling and modelling. It is a very well written paper (with some minor suggestions for improvement below) and the gathered data seems to be analysed with precision.

We thank the reviewer for the careful and encouraging assessment of our manuscript. Below, we address each point raised by the reviewer.

However, due to the limited amount of samples and not having a reference (no biomass) in the different thawing conditions, it is very hard to draw conclusions out of the results. The authors should therefore be careful in their statements and conclusions. I will elaborate on this more below.
We agree that it is important to show a reference for root and rhizome quantity as, for example biomass and root total length. However, we did already include root and rhizome biomass per thaw stage in Fig. 2 in the main text and show root total length variation along the thaw gradient in the Appendix (Fig. B4). As per Reviewer 1 comment, we have now also added mention of root total length variation along the thaw gradient into the main text in the results. Nonetheless, we agree that the small sample size makes drawing conclusions challenging, and discuss this more in the discussion section:

L438 onwards (also see our response to Reviewer 2 comment related to environmental variables along the thaw gradient): “However, due to the low sample size we were unable to separate the effects of plant traits and soil moisture in multivariate models, and larger sample sizes are recommended to analyze the interactions between soil moisture and plant belowground traits in future studies.”

L613: "Taken together, the temporal variation in root and rhizome traits may have contributed to CH_4 fluxes but belowground trait sampling with larger sample sizes throughout the productive season is needed to investigate these relationships further."

L429: "SRL was highest and root diameter lowest at the partly thawed stage, which could reflect increased resource acquisition particularly for shrubs (Bergmann et al., 2020), but further research with larger sample sizes are needed to look into the potential changes in shrub resource acquisition."

Further, for persons who do not work in permafrost regions (like me) it would be very helpful to get a better explanation what kind of processes are relevant in this system and specifically what is changing when thawing occurs. Also explain what a palsa exactly is.

We have added more details about permafrost peatland ecology and biogeochemistry and explain what palsa is in the introduction:

L40 onwards: "Palsas are approximately 0.5-10 m high peat hummocks with a frozen core of peat and mineral soil. They form as a result of water-saturated peat freezing in winter and the dry surface peat protecting the frozen peat in summer, raising the peat above the surrounding mire (Luoto et al., 2004). In northern Fennoscandia, permafrost thaw has formed transitional gradients from frozen palsas and peat plateau to permafrost-free bogs and fens (Luoto et al., 2004; Olvmo et al., 2020). Following palsa collapse, soil moisture increases, shifting the system from an ombrotrophic bog-like system to a minerotrophic fen. Vegetation composition shifts from shrub-dominated on palsas to graminoid-dominated in fens, and soil redox and pH change, influencing methanogenic CH_4 production, methanotrophic CH_4 consumption, and CH_4 transport from the soil to the atmosphere, and net CH_4 fluxes (Perryman et al., 2020; Turetsky et al., 2014; Varner et al., 2022)."

Overall, I think the study is a relevant stepping stone to a wider study with or more sites, or more samples from this site. I would recommend it for publishing after revisions, where 1) statements and conclusions are nuanced, 2) other explanatory variables are explored (if possible), and 3) where authors give suggestions on what is needed to link below-ground biomass trades to plant-mediated CH4 transport based on what they have learned from their study.

We thank the reviewer for the helpful feedback and have implemented it in the revised manuscript.

Concerns

If I look at Figure 3 and Figure B6, I see mainly a trend between thaw stage and CH4 fluxes. As the authors state in the discussion, other drivers for CH4 fluxes are soil moisture, water table depth, substrate availability and (not mentioned) temperature. There is a clear increase in CH4 fluxes with the increase in thawing of permafrost. How do the above-mentioned drivers change with the thawing gradient? It would be very relevant to know how the below-ground biomass characteristics are related to the drivers mentioned above. If it's possible then a multi variate regression or a mixed effect model could be done to exclude the effect of other drivers than below ground biomass characteristics. Or add these drivers to you PCA analyses. Authors state that 'we studied the permafrost thaw-driven CH4 flux variation with a plant trait-based approach with a focus on belowground traits' (L392), I think you can only do that if you exclude the other factors.

This is an important point. Due to the low sample size and degrees of freedom, we were unable to run linear mixed models and multivariate linear regressions to separate the effects of other environmental CH_4 flux drivers, such as soil moisture, temperature and water table level. However, we did explore the potential effect of plant green area and peat temperature on CH_4 fluxes by looking at correlations between green area, peat temperature and CH_4 flux at the different CH_4 flux periods (the same CH_4 flux values that were used in the trait-CH_4 flux regressions). We then qualitatively compared these relationships to the trait-CH_4 flux regressions and Kendall correlation coefficients. We have shown these results in Fig. B10 (Fig. B8 in the revised manuscript) in the Appendix and included text about these results in the Results (3.2) section.

We also agree that it is important to try to disentangle the effects of environmental variables and traits on CH_4 fluxes along the thaw gradient. In fact, as has been found in previous studies at Stordalen and other wetlands, water table level is an important CH_4 flux driver. However, water table level has not been measured in Stordalen since 2017, and we were unable to use it as a predictor of CH_4 fluxes. We did obtain soil moisture data from each CH_4 flux chamber location from 2024 and 2025, and observed a positive relationship between soil moisture and CH_4 flux along the thaw gradient. We originally decided to not include this data due to data license issues. During the revisions, we have now worked out a solution for this, and have now added similar correlation analyses for peat moisture and CH_4 flux period values as for the other environmental variables (peat temperature and green area). The peat moisture data (aggregated to daily medians) is shown in Table C3 in the Appendix.

Even though peat moisture and water table level are important CH_4 flux drivers also at Stordalen, as we mention in the discussion, high soil moisture also drives aerenchyma formation particularly in herbaceous plant roots (a relatively well-known phenomenon in plant ecology). Thus, we think that the CH_4 flux trends following thaw stage gradient does also reflect changes in the root traits, especially in root porosity which can be a proxy for plant-mediated CH_4 transport. Due to this, we would also expect peat moisture and root tissue density to be collinear in linear (mixed) models and we would likely be unable to include them in multivariate models if we had larger sample sizes. Nonetheless, we have now added more discussion of the importance of peat moisture driving CH_4 fluxes possibly simultaneously with increasing root porosity (i.e., decreasing root tissue density) in Stordalen.

New sentences:

L438 onwards (beginning of the first paragraph of 4.2): "The increasing peat moisture and associated changes in belowground plant traits contributed to the increasing CH_4

fluxes along the permafrost thaw gradient. Given our exploratory results (see 3.2 and Fig. B8) and earlier studies conducted at Stordalen (Holmes et al., 2022; Malhotra and Roulet, 2015), the increasing peat moisture was likely one of the primary drivers of the increasing CH_4 fluxes along the thaw gradient. However, due to the low sample size we were unable to separate the effects of plant traits and peat moisture in multivariate models, and larger sample sizes are recommended to analyze the interactions between peat moisture and plant belowground traits in future studies. Nonetheless, the univariate relationships between plant belowground traits and CH_4 fluxes indicated 1) maintained carbon substrate provision and 2) increasing plant-mediated CH_4 transport across the permafrost thaw gradient. "

L471 onwards: "Plant-mediated CH_4 transport may have been pronounced in the fully thawed stage with high peat moisture, herbaceous plant coverage, and low porewater CH_4 concentrations (Table C1 and Fig. B8, B11), indicating plant CH_4 uptake. "

L472: "As low root and rhizome TD indicates higher porosity (Ye & Ryser, 2022), the negative relationships between root TD and CH_4 flux suggest increased plant-mediated CH_4 transport in response to increasing peat moisture. "

We have also added peat temperature as a potential driver of CH_4 fluxes in Stordalen in the discussion (L386-390): "The increased CH_4 fluxes with permafrost thaw in Stordalen are driven by a complex network consisting of drivers such as higher water table level and increased anoxia (Holmes et al., 2022; Malhotra & Roulet, 2015), higher peat temperatures at the end of growing season (Mollenkopf et al., 2026), …"

In this context, we have now changed the highlighted sentence to: "we explored the effect of belowground plant traits on CH_4 fluxes." (L392), to avoid possible confusion and to highlight that we looked at univariate instead of multivariate relationships to study the trait-CH_4 flux connections.

Further, I think the authors could have done some more investigation in looking into relationships between GPP-CH4 and diurnal cycles in CH4 fluxes to give more evidence for plant mediated transport.

Good idea- we have now explored diurnal GPP-CH_4 flux relationships and added the resulting plots in the Appendix (Fig. B1). However, as the focus of this study was more on the daily to productive season time scale, we have limited these additional analyses to a couple of sentences in the discussion similar to the other GPP analyses and discussion (L519-522):

"In addition, gross primary production (GPP), a proxy for plant-mediated gas transport (Knox et al., 2021), peaked in July and August (max monthly medians: 3.87 and 2.79 µmol CO_2 m^{-2} s^{-1}, respectively; Fig. B1). Concurrently, CH_4 fluxes at the partly and fully thawed stages were slightly higher during nighttime (Fig. B1). Both of these GPP and CH_4 flux trends could further indicate seasonally (via higher herbaceous plant biomass) and diurnally- (via stomatal opening and closure) varying plant-mediated CH_4 transport. However, as GPP and CH_4 flux peaks did not coincide in

the same hourly time periods, further research into diel CH_4 fluxes and plant-mediated CH_4 transport is needed (Fig. B1) (Knox et al., 2021). "

The following sentence is due to the above mentioned uncertainty too speculative 'SRL was highest and root diameter lowest at the partly thawed stage, possibly reflecting increased resource acquisition particularly for shrubs with high SRL and low root TD' .

We have now changed this sentence to: "SRL was highest and root diameter lowest at the partly thawed stage, which could reflect increased resource acquisition particularly for shrubs (Bergmann et al., 2020), but further research with larger sample sizes is needed to investigate the potential changes in shrub resource acquisition."

dC13 and ac are measured and it seems that the results are interesting (Fig. B13). Maybe it's worth adding that to the results, but also explain a bit better the mechanism behind the results and why it is relevant. It would help to make two who dC13 and ac in separate plots. Be careful with statements about CH4 oxidation being higher or lower. It's not clear for the data isn't it. Or if it is, then please explain a bit better why it is.

We made the decision of keeping the porewater CH_4 isotope and concentration results in the Appendix to keep the focus of the main text on the trait-CH_4 flux relationships, where the pore water data provided supporting information on the depth-resolved trait-CH_4 relationships.

As suggested, we have now separated α_C and ^{13}C-CH_4 into their own separate plots in Appendix Fig. B11 (in the revised manuscript).

We included discussion about CH_4 oxidation because lower root tissue density can also reflect increased O_2 transport to the soil. Some studies at Stordalen have also found increased methanotrophic CH_4 consumption with permafrost thaw and partly suggested that this could be related to increased O_2 transport from aerenchymatous plant roots. It is true that drawing conclusions about CH_4 oxidation based on the isotopic data can be uncertain, and we have now added one sentence about this in the discussion (in L487-498): "In addition, during CH_4 oxidation, methanotrophs preferentially consume lighter $^{12}CH_4$, enriching the remaining CH_4 pool in ^{13}C while producing isotopically light CO_2 (Whiticar, 1999). However, isotopically light CO_2 could also indicate less methanogenesis instead of increased methanotrophy, and rhizospheric $\delta^{13}CH_4$ enrichment can also result from faster plant $^{12}CH_4$ uptake and increased plant-mediated CH_4 transport (Chanton, 2005). "

Details

L110-117: This part could be in the introduction, which helps to understand the system.
As this part is very specific to Stordalen, instead of moving this text to the introduction, we have added more details of the general variation in soil biogeochemistry and vegetation composition along peatland permafrost thaw gradients in the introduction. Related to this, we now also explain what palsas are in the introduction.

L40 onwards: "Palsas are approximately 0.5-10 m high peat hummocks with a frozen core of peat and mineral soil. They form as a result of water-saturated peat freezing in winter and the dry surface peat protecting the frozen peat in summer, raising the peat above the surrounding mire (Luoto et al., 2004). In northern Fennoscandia, permafrost thaw has formed transitional gradients from frozen palsas and peat plateau to permafrost-free bogs and fens (Luoto et al., 2004; Olvmo et al., 2020). Following palsa collapse, soil moisture increases, shifting the system from an ombrotrophic bog-like system to a minerotrophic fen. Vegetation composition shifts from shrub-dominated on palsas to graminoid-dominated in fens, and soil redox and pH change, influencing methanogenic CH_4 production, methanotrophic CH_4 consumption, and CH_4 transport from the soil to the atmosphere, and net CH_4 fluxes (Perryman et al., 2020; Turetsky et al., 2014; Varner et al., 2022)."

L134: -2 is in superscript
This was an accident and is now fixed.
L155, 166: Peat and soil are used in a similar way (peat temperature or soil temperature?)
Good catch- we prefer "peat temperature" and have now changed this throughout the manuscript.

L222: Filtering on R2 only could lead to removing very low fluxes. Adding the actual slope to the filter (allowing a higher R2 with lower slopes would help)

In principle, filtering based solely on R2 can bias against low fluxes when measurements are close to the detection limit. However, in our dataset, this effect appears to be limited because the automated chamber system has high analytical precision, and particularly for the partly thawed and fully thawed plots CH_4 fluxes are well above the detection limit. In these cases, low fluxes do not necessarily correspond to low R2 values. Instead, low R2 values are more likely associated with measurement artefacts (e.g. chamber leakage, pressure effects, or non-linear concentration changes) rather than true low fluxes. We evaluated the effect of R2-based filtering and found that excluding low-R2 measurements has minimal impact on mean CH_4 fluxes across plots. Based on comparing CH_4 fluxes before and after
applying a 95% threshold R2 criterion for a subset of the data (days 101–250 in 2023), only a small proportion of CH_4 fluxes were removed in partly thawed (2%) and fully thawed (1%) plots, with negligible changes in mean fluxes (partly thawed: 35.55 to 35.90 mg m^{-2} d^{-1}; fully thawed: 85.45 to 86.05 mg m^{-2} d^{-1}). Even in the intact palsa plots, where a larger fraction of fluxes (18%) was removed, mean CH_4 fluxes remained within a similar range (7.7 to 9.3 mg m^{-2} d^{-1}).

Nevertheless, we have updated the methods to provide more detail to reflect the QA/QC workflow provided with the dataset, which includes regression diagnostics, manual quality flags, and concentration-based filtering criteria. The new sentence:

"The CH_4 flux data were fit using linear regression. The data were quality-checked using regression diagnostics where CH_4 fluxes outside of significance thresholds at 95% and 90% confidence levels were filtered out (Snedecor and Cochran, 1989), as well as manual quality flags that were used to filter out data points affected by known

instrumental issues."

New reference added:

Snedecor, G. W. and Cochran, W. G.: *Statistical Methods*, 8th Edn., Iowa State University Press, Ames, 1989.

We have also rerun all analyses using the fully QA/QC'd CH_4 flux dataset and updated the results where necessary.

L243-245: I don't understand what that means. And for which results is this used?

This was used for determining the CH_4 flux period values (early, middle and peak CH_4 flux within the productive season) from the daily-aggregated CH_4 flux data. For this, we fit a GAM where the date was the explanatory variable of CH_4 flux (response) so that we can get general estimates of CH_4 flux for each date and then calculate the different CH_4 flux period values for each chamber. Delwiche et al. (2021; https://doi.org/10.5194/essd-13-3607-2021) did a similar thing but with a Gaussian curve because they had full year CH4 flux data. We had CH_4 flux data only from the growing season, so we used a GAM which was able to capture the general CH_4 flux trend during the productive season better than a Gaussian curve.

We have now improved the sentence and the sentence before it as follows: "To explore the variation in the trait-CH_4 flux relationships during the productive season, we calculated CH_4 flux period values (early, middle and peak CH_4 flux) by fitting Gaussian generalized additive models (GAM) with identity link function for daily median CH_4 flux data per chamber with function gam from package mgcv (Wood, 2011, 2017). In the models used for determining CH_4 flux period values, CH_4 flux (response variable) was transformed to approximate normality using inverse hyperbolic sine and date was included as an explanatory variable in a thin plate regression spline."

L293: This is a very long title

We shortened the title to: "More herbaceous roots with decreasing tissue density".

L298: 1.5x lower

Fixed.

L301: 22.2x 22x (remove decimal to be consistent)

We have used these decimals for the other values in this section as well, and did not show the decimal for the "17x" because it was 17.006≈17. Thus, we have instead added ".0" to the sentence: "Summed root biomass and surface area (SA) were 22.2x and 17.0x lower, respectively…"

L312: Introduce the abbreviation CV, and add for between mean and intact

Fixed: "Most of the root biomass was found in the top 10 cm for shrub (coefficient of variation CV and mean for intact:..."

L323-328: Could you show all results in a graph? That would be easier to follow

These results were in fact shown in two graphs: Fig. 3 (only for root tissue density, diameter and specific root length from the middle CH_4 flux period) and for all CH_4 flux period values in Appendix Fig. B6 and B7. We chose to show only the root tissue density, diameter and specific root length in Fig. 3 from the middle CH_4 flux period because the trait-CH_4 flux relationships did not vary a lot within the productive season. However, as per Reviewer 2 comment related to replacing Fig. 5 with Fig. B6, we have now replaced Fig. 5 and Fig. 3 with a figure that combines the trends between root tissue density, SRL and diameter and CH_4 fluxes per PFT and across PFTs (biomass-weighted) for each CH_4 flux period. Similarly, we replaced Fig. 4 and Fig. 5 with a figure showing trends between rhizome biomass, surface area and diameter per PFT and across PFTs (biomass-weighted diameter, summed surface area and biomass) for each CH_4 flux period. The rest of the root and rhizome traits were kept in the Appendix. Thus, we have now removed the values (e.g., R2s) shown in the figures main text (results 3.2) to make it easier to read.

L382-383: why is it relevant to know if CH4 is produced by hydrogenotropic or acetoclastic methanogenesis?

To our knowledge, a shift from hydrogenotrophic to acetoclastic methanogenesis could suggest a change to a more root exudate-driven methanogenesis (e..g, Saarnio et al., 2004 https://doi.org/10.1007/s11104-005-0140-3 and Ström et al., 2003 https://doi.org/10.1046/j.1365-2486.2003.00655.x). We discuss this in more detail in section 4.2 (L455-460) in relation to shrub root traits.

We have now added a clarifying sentence about this after the highlighted sentence: "Shifts from hydrogenotrophic to acetoclastic methanogenesis can indicate increased root exudate-driven CH_4 production (see 4.2) (Saarnio et al., 2004; Ström et al., 2003)."

L416: How heterogeneous is your plant cover? Can differences not be explained by that or the sample size?

It is difficult to estimate the exact cause of these differences since the referenced studies used different root sampling methods than us and they did not report all the steps taken. However, we agree with the reviewer's point, and we have now added a new sentence addressing the uncertainty caused by the low sample size and the fact that we combined different species in our root samples, which the other studies did not do: "In addition, our root samples may have consisted of a different mix of species than in Hough et al. (2022), which together with the low sample size, may have influenced these results."

L488-490: It is not clear what is the result of this study and what not. It's also not clear why this is relevant.

We think it is important to discuss the potential CH_4 oxidation along the thaw gradient, as the decreases in root tissue density (and thus increases in root porosity) could also increase O_2 transport to the soil and thus CH_4 consumption in the peat. However, we agree that mentions of methanotrophic community structures are unnecessary details in the context of this study, and have streamlined the sentence to clarify that previous studies reporting increased oxidation with thaw could be related to our observation of increased root tissue density.

We have now modified the sentences as follows:

"Simultaneously to plant-mediated CH_4 transport, herbaceous roots may have enhanced rhizospheric CH_4 oxidation. Previous studies at Stordalen have reported shifts in methanotroph communities with thaw as well as an increase in CH_4 consumption, which may result from greater plant-mediated rhizospheric oxidation (i.e., more O_2 transport with lower root TD) and acetoclastic methanogenesis (Perryman et al., 2020; Singleton et al., 2018). "

L498: '…with belowground traits for the first time…', what does that mean?

We wanted to highlight the significance of our paper here, but we agree that this part can make the sentence a bit hard to understand. Thus, we have removed this from the sentence: "Thus, based on the lower αC (i.e., maintained acetoclastic methanogenesis) at 20-44 cm depth, and the strongly negative relationships between root TD and CH_4 fluxes (i.e., decreasing amount of aerenchyma is related with lower CH_4 fluxes and vice versa), it seems that the CH_4-oxidizing effect of herbaceous plants particularly in the fully thawed stage is overshadowed by increased carbon provision for methanogenesis and enhanced plant-mediated CH_4 transport."

L500-501: '…differed only slightly in strength.' What does this mean, that there is a linear trend in every season and only slightly differ? Are they significantly different? If not, don't write it.

We meant here that the linear trends only differed slightly. We have now modified this sentence as follows: "The relationships between the static belowground traits and CH_4 fluxes (early, middle, peak, and season median) did not vary strongly within the productive season."

L504: In figure 5 I mainly see a relation between the three thawing stages which can be related to many different factors. It would be better to replace Figure 5 with figure B6, that one is clearer.

We agree, and we have now replaced Fig. 5 with Fig. B6 (only for root tissue density, diameter and specific root length, and kept the rest of the traits in the Appendix to save space) and combined it with Fig. B7 (biomass-weighted root traits only for root tissue density, diameter and specific root length and the rest in the Appendix).

Similarly, we also replaced Fig. 4 with Fig. B8 and B9 but only for rhizome biomass, surface area and diameter, and kept the rest in the Appendix to save space).

L504: ‘strongly associated’ what does associated mean? (same in next sentence). Be specific about that

By “associated”, we mean the beta coefficients and R2s of the linear regressions between the traits and CH_4 flux period values. To make this clearer, we now say “related” and explain the statistical basis in parentheses.

We have now clarified this as follows: “In contrast to our hypotheses, shrub root traits were more strongly related (i.e., higher linear regression β and R2) with middle and peak CH_4 fluxes whereas herbaceous root (TD) and rhizome (SA) traits were strongly related with CH_4 fluxes throughout the season.”

L505: ‘…root porosities not responding strongly to changes…’ this statement is too big for the results you have.

Agreed- we have now removed this sentence from the paragraph.