General Comments:

This study determined the gas diffusivity of forested peat and extracted the macropore networks from µCT images of peat to simulate the gas diffusion along the networks. The authors highlighted that the combination of the µCT and pore networking modeling provide reliable estimation of gas diffusivity of peat. This is a very interesting story because our understanding of the pore structure of fen peat as well as the gas diffusivity is indeed quite limited. The novelty of the manuscript is high and it is well written. But a moderate revision is necessary before publication:

My major concerns are:

1. The pore structure of peat is missing and the discussion is a little weak.

The authors analyzed the pore structure of peat but the pore features (e.g. tortuosity, pore connectivity, pore size distributions) are not shown and discussed. These parameters are quite important for gas diffusivity but were only mentioned in several sentences during discussion (e.g. line 413). I think the quality of the manuscript will be improved greatly if the authors could give solid discussion based on the parameters derived from peat soils. Maybe the authors have published this information previously, still a summary of these parameters is necessary.

2. The shrinkage information is unclear.

One unique property of peat is "shrink-swell", which is much greater than mineral soils (e.g. clay). This is also the reason that our understanding of the gas diffusivity of peat is limited. The authors indicated that the gas diffusion measurement may be affected by soil shrink. I think it is necessary to provide more detailed information on soil shrink: percent of volume change and at which pressures and for which soils the gas diffusion values are less affected by soil shrink.

Specific comments:

1. line 12, this conclusion is unclear. From table 1, for top soil (0-5 cm) the gas diffusivity is high at -1 kPa, but the air-filled porosity is also high 30 vol%. This is not near saturation. For deeper peat (40-45 cm), the gas diffusivity is low though it is more near saturation.

2. line 14, or you mean the traditional gas diffusivity models?

3. lines 37-39, "unsaturated" is a quite wide range. I would suggest using "when soil moisture is high".

4. lines 48-50, not true. Or you could refer to "natural peat" or "pristine peat". For degraded peat, the density as well as macroporosity decreases with depth.

5. line 267-268, this sentence is not necessary.

6. line 271, see above.

7. Figure 4, why select this pressure head, not others. At this pressure head, soil shrink occur and it affect the results the most (line 341). Also, this figure shows the only the top soils do not follow the function well. Because it has the highest macroporosity (42 vol%). This value is comparable to the total porosity of mineral soils. I think the authors could provide more detailed information to highlight the unique structure of peat.

8. lines 314-323, I think the authors could discuss a little more. Generally, peat types (fen, bogs) and decomposition/degradation stages (Liu and Lennartz, 2019) are two crucial factors affecting peat structure. I think the authors could compare the gas diffusivity for fens and bogs (from previous publications) at a comparable decomposition level (e.g. bulk density values).

9. Line 335, the pore structure (e.g. connectivity) of the samples should be provided.

10. lines 345-354, I do not understand why it is necessary to give this discussion. Or, just concise the paragraph.

11. lines 388, Actually, you could estimate the pore size according to the capillary rise equation.

12. lines 389-392, Not so true. I mean, you determined the weight of the samples. The air-filled porosity could be justified according to the weight differences rather than using particle density or total porosity.

13. Section 4.3, I think the authors could explain the reasons together with highlighting the unique structure of peat.

14. Table 3. Please check the values again, especially for R^2.

Reference:

Liu, H., & Lennartz, B. (2019). Hydraulic Properties of Peat Soils along a Bulk Density Gradient– A Meta Study. Hydrological Processes, 33, 101–114.