Review #1

This manuscript describes an effort to make the representation of BNF more realistic in LPJmL. The main results are that changing the representation of BNF – from a less-mechanistic function of AET to a more-mechanistic dependence on temperature, moisture, and N limitation – decreases overall estimates of BNF and modifies the spatial distribution, resulting in a better overall fit to data. This is a worthwhile effort, and from what I can tell the work is solid. My hope is that my feedback below will improve the work.

We cordially thank the reviewer for their positive evaluation of our manuscript and the constructive feedback. Below we provide a point by point response to their feedback and suggested changes to improve the manuscript.

Major/overall suggestions:

My main areas of feedback are (1) a greater focus on relevant empirical work, (2) greater discussion of how the implementation of BNF compares to other models, and (3) more explanation of the methods.

(1) I understand that this is a modeling study, but there is a lot of relevant empirical literature that is not referenced. For example, the parameters describing responses to moisture and temperature are taken from Yu & Zhuang, which is another modeling study. That's fine, but I would like to see more explanation of how those values compare to actual measurements of these quantities. As another example, your BNFfrac (see below as well) is a commonly measured quantity in N fixation work at the plant scale. Particularly for agricultural systems, there are large amounts of data. How do your results compare to empirical data? There are a few papers cited in the discussion about how N fixation varies as a function of N limitation, succession, etc., but there is a lot of work in these areas, and the discussion reads as if these were the first few that came up in a search rather than a synthesis of deep reading on the subject.

We agree that an extended comparison to empirical literature will strengthen the discussion and improve the overall quality of the manuscript. We propose to incorporate the findings of the articles listed in the table below. If possible, we selected the studies according to two criteria to limit the scope: First, we included recent meta analyses and reviews to capture the extent of available literature and, secondly, we refer to early experimental work to highlight how well this knowledge is already established. We trust that these will provide sufficient empirical context for a model development study.

Process	Literature
Temperature limitation	(Meyer and Anderson, 1959; Montañez et al., 1995; Rousk et al., 2018; Yao et al., 2024)
Water limitation	(Rousk et al., 2018; Serraj et al., 1999; Valentine et al., 2018; Yao et al., 2024)
Carbon cost and NPP limitation	(Kaschuk et al., 2009; Patterson and Larue, 1983; Ryle et al., 1979; Voisin et al., 2003)
BNF_{frac} or $\%N_{dfa}$	(Herridge et al., 2008; Salvagiotti et al., 2008)

(2) The discussion of other model implementations of more mechanistic BNF could also be improved. Ma et al. (another version of LPJ) and Yu & Zhuang (TEM) are referenced most heavily, and Fisher et al. and Davies-Barnard & Friedlingstein are also mentioned, but there are many other implementations out there ranging from land models to ecosystem models. Kou-Giesbrecht et al. 2023 (cited in the ms) has a nice table that lists a few of the TRENDY models that incorporate mechanistic representations of BNF: CLASSIC, CLM, DLEM, OCN. There are other non-TRENDY models that have been developed that have been applied at large spatial scales – LM3/LM4 and QUINCY come to mind – and there are tons of ecosystem models (ED, MEL, CENTURY, etc.) that do something similar. Readers will want to know how your implementation compares.

Thank you for this comment. We agree that this will improve the discussion and propose to conceptually compare our approach against a selection of the approaches synthesized in Kou-Giesbrecht et al., 2023 and Liu et al., 2011.

(3) Explanation of the methods: I'd like to see a clearer description in the methods of how the versions were evaluated. I'd also like to see more detail about how N limitation is calculated, given that this is the key aspect of the paper. In particular, how is Ndeficit calculated?

We propose to rename the section evaluation data to model evaluation and extend it by a description of the equations used for the global and site specific evaluation. We further propose to update the modelling protocol to thoroughly describe the simulations conducted for the site-specific evaluation.

To provide a better picture on the N limitation we will add an overview of the N demand, uptake and stress components as described in von Bloh et al. (2018) including the main equations. We will also summarize how the N deficit is calculated based on N demand and passive and active N uptake.

Minor suggestions:

Given that you've stated that you're modeling all BNF, not just legume-associated BNF, I suggest changing the name of f_{legume} to f_{fixer} or something like that.

Thank you for this suggestion which we will adopt.

Fig. 3 caption needs to specify what "DBF" is. I assume Davies-Barnard & Friedlingstein, but it would be nice to see in the caption, particularly given that there are other meanings of DBF (e.g., deciduous broadleaf forest).

We will include the explanation for DBF which is indeed Davies-Barnard & Friedlingstein in the caption.

The color scales on the global figures overemphasize the high range, making it hard to see variation in the lower range. For example, Fig. 3 looks largely like a map of agricultural BNF.

We agree that the color scale can be improved and propose to use the smooth rainbow scale from the khroma package (Frerebeau et al., 2024) that is able to show difference in the higher and lower part of the range.

189: In the empirical literature, what you describe as BNF_{frac} is called $\%N_{dfa}$ (percent of N derived from fixation activity or derived from the atmosphere, depending on who you ask). It might help your paper to make the connection.

Thank you for establishing the connection. We will adopt the term and include the variable in our evaluation (see also response to major comment 2).

197: It's true that 4 g $N/m^2/yr$ is a lot lower than 15, but 4 g $N/m^2/yr$ is still a huge difference.

We will rephrase this to highlight that 4 gN/m^2 is still substantial.

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