We thank the reviewer for their thorough and constructive feedback. We are pleased that the methodological contribution of this study and the relevance of integrating fire and grazing management into LPJmL were appreciated. Below, we provide a point-by-point outline of how we plan to address each of the reviewer's comments in the revised manuscript.

All comments related to the figures are grouped together at the end. Minor comments, such as typos or small wording changes, are not listed individually but will be integrated as proposed.

Major comments:

> **The main thing I'm concerned about here is how grazed nitrogen is handled in the model. There's no citation in the Methods, as far as I noticed, pointing to information about how LPJmL grazing works at all, actually. N isn't mentioned alongside C at L131-133 as being partially returned to the soil via animal waste after grazing. That initially led me to think it wasn't. Then at L267, "manure (in grazing systems)" is mentioned as one input to the soil. But what fraction of the consumed N? And is it only feces or is it also urine?**
>
> **[…]**
>
> **If a realistic fraction of the grazed N isn't returned to the soil, I have serious doubts about the LPJmL model's fitness for the purpose of analyzing impacts of grazing on soil N and thus leaf C:N ratio too. See Selbie et al. (2015, DOI 10.1016/bs.agron.2014.09.004): "Ruminants excrete as much as 70–95% of the nitrogen (N) they consume."**

Thank you for highlighting this important point. This issue was also raised by the Reviewer 2, and we have provided a detailed response addressing it in our reply. For completeness and clarity, we kindly refer Reviewer 1 to that response, where we clarify that 66.7% of the nitrogen contained in the grazed biomass is returned to the soil as manure including feces and urine.

> **Then again, in Fig. 10, neither manure nor urine are explicitly mentioned. They might be included in "harvest N" with that color showing net harvest N loss, but that's not explained. And finally, Fig. 11 does have manure again.**

Thank you for pointing this out. Figure 10 represents the ecosystem nitrogen budget, which includes only external nitrogen fluxes. Since manure is not treated as an external nitrogen input in our model setup, but a conversion of plant nitrogen it is not included in this figure. The component 'harvest N' in Fig. 10 contains only the nitrogen that is grazed and removed from our model domain so that it does not include the nitrogen in the manure.

In contrast, Figure 11 focuses on the soil nitrogen budget, which explicitly accounts for manure as an input to the soil nitrogen pool. The distinction between these two perspectives is clarified in the figure captions, both of which refer to the section "Nitrogen in- and out-fluxes" (previously Section 2.4.3, now moved to Section 2.1.4), where the composition of the budgets is described in detail.

To clarify the point raised regarding manure, we have added explicitely that manure is excluded from the ecosystem budget in its description :

The ecosystem nitrogen budget is determined by the balance of nitrogen input, biological nitrogen fixation (BNF) and atmospheric deposition, and nitrogen outputs, including leaching, *denitrification, volatilisation, plant uptake, harvest nitrogen (in grazing systems excluding the part returned to the soil as manure) and NOX emissions from fire (in burning scenarios).*

> **If the N analyses are kept, some text needs to be added to the Methods describing biological nitrogen fixation (BNF) in LPJmL. Are both symbiotic and asymbiotic BNF represented? How do they work?**

We thank the reviewer for raising this important point. This issue was also brought up by Reviewer 2, and we have provided a detailed explanation in our response to their comment. In short, we clarify how BNF is computed in LPJmL providing the equation and how we will explained it in the manuscript.

Other comments

> **1) I would like to see some text added to the Discussion or Conclusion about what work would be needed in order for this feature to become commonly enabled in LPJmL runs. Is it just livestock density maps (both historical and for future scenarios) that are holding it back?**

The main prerequisite for applying the pasture burning version of LPJmL and the Chalumeau module in other regions is a solid understanding of local burning practices. In this study, we focused on Brazil, where we could base the implementation on existing literature and documented fire management practices. While the pasture burning functionality itself is flexible and can be technically applied to other regions, its meaningful use requires region-specific calibration regarding fire season. Indeed, the broader application of the Chalumeau algorithm would require a careful reassessment, especially in temperate and polar regions. The algorithm relies heavily on climate inputs and seasonal patterns, which may not translate well across different biomes without further development and validation. We have added a few lines addressing these aspects in the newly titled “Limitations and Outlook” section of the manuscript (l. 441):

Applying the pasture burning version of LPJmL and Chalumeau module beyond Brazil would require region-specific information on fire management practices. While the current implementation is technically flexible, meaningful application in other regions depends on adapting fire-use assumptions. In particular, the Chalumeau algorithm, which is driven by seasonal and climatic constraints, should be carefully re-evaluated before application to temperate or polar regions.

> **2) The Appendices are strange. Appendix A has only one figure—why not combine the two Appendices? That figure, Fig. A1, is also the very last to be mentioned in the main text (and only as “Sec. A”, not “Fig. A1”); it should thus be last in the Appendix as well. Finally, there are four Appendix figures not mentioned in the main text: Figs. B2–3 and B5–6.**

We acknowledge the inconsistency in appendix structure and figure referencing. Appendices A and B have been merged into a single section. We have revised the order of figures so that Fig. A1 (currently referenced last) appears at the end and we have ensured that all appendix figures are explicitly referenced in the main text with appropriate labels.

> **6) L157-166 (Sect. 2.2.1): Since the Brunel et al. (2021) and Waha et al. (2012) papers are not open-access, more detail should be given here (or in an Appendix/Supplement) on the Chalumeau algorithm and its implementation. For instance, how often is the burning date updated? Does it use a rolling window to calculate seasonality variables?**

What's the difference between the "burning date" vs. the strategies (e.g. "early spring")? Etc.

Thank you for the suggestion. We will include additional details on the Chalumeau module in the Appendix to improve clarity and accessibility. Briefly, Chalumeau identifies the dormant season (DS) and extracts burning dates using daily temperature and precipitation data. A 10-day moving average for temperature-driven seasonality and a 10-day moving cumulative sum for precipitation-driven seasonality are used to identify the dormant season as either the winter or dry period. Then, depending on the chosen burning strategy, a single burning date is extracted per grid cell and DS.

8) L224-233: Is other fire allowed to happen during these experiments? I.e., are the only ignitions allowed due to intentional pasture management burning, or is the rest of SPITFIRE operating at the same time?

Only the intentional burnings are applied to the pasture during the simulated experiment. Natural fires do not occur. We clarify this point in the Section 2.3.2, Model configuration and experimental setup adding this sentence (l.229) :

Burning practices are the only fires applied to the pasture during the experiment.

9) L227-229: It's not until this sentence until I understood what this paragraph was supposed to be describing; until then I was pretty confused. Please move it to the top of the paragraph and edit as needed for flow.

Upon re-reading the section, we agree that the structure was somewhat confusing. Following your suggestion, we have moved the respective sentence to the beginning of the section (l.209), hoping that this will better guide the reader through the description of the experimental setup.

10) L230-231: I'm not sure I understand this correctly. How many replicates does this result in? 2 + 5 + 10 = 17?

Thank you for pointing this out. Indeed, the number of replicates corresponds to the length of the burning frequency: the 2-year frequency scenario includes 2 replicates (starting in year 0 and year 1), the 5-year frequency includes 5 replicates (starting from year 0 to year 4), and the 10-year frequency includes 10 replicates (starting from year 0 to year 9). We have clarified this in the manuscript by adding the following sentence in (l.231):

This results in 2, 5, and 10 replicates for the 2, 5, and 10 year burning frequency scenarios respectively.

11) L233: Are the four strategies something that the Chalumeau algorithm produces for each gridcell? Or are they things you switch between for different experiments?

Thank you for this question. The burning strategy is provided as an input parameter to the Chalumeau algorithm for each experiment. Based on the selected strategy, Chalumeau determines the corresponding burning dates. We will clarify this point in the Supplement, as mentioned in our response to comment 6.

14) L262-268 (Sect. 2.4.3): Why is this in the "Post-processing" section? It would be more appropriate near Sect. 2.1.3 ("Soil nitrogen pools").

We agree that the paragraph does not fit well within the "Post-processing" section. However, since it addresses the broader ecosystem nitrogen budget rather than soil nitrogen pools alone, we have moved it after Section 2.1.3. We think that this new placement ensures better alignment with the content and improves the overall structure of the Methods section.

17) L288: What nitrogen deficit? It hasn't been previously established that NPP is Nlimited under any conditions or treatment.

Thank you for this observation. We have revised the sentence to clarify that the nitrogen deficit in leaves is a result of the burning practices (l.288):

Burning practices lead to a nitrogen deficit in leaves, significantly affecting the nutrient balance of the vegetation.

19) L297–299: How is this result possible?

Thank you for your comment. This result is indeed discussed in more detail in Lines 406–419 of the Discussion section. To summarize it, the difference in responses between biomass pools (AGB) and fluxes (dry matter intake) arises from their distinct sensitivities to disturbances. While AGB shows a gradual, cumulative decline over time due to repeated grazing and burning, intake (a flux) initially drops but stabilizes as the system adapts. This is because intake responds more directly to the balance between net growth and losses: as biomass decreases, fire intensity and thus disturbance also diminishes, allowing intake to reach a new, stable equilibrium despite lower overall biomass.

To improve clarity for the reader, we now include a brief indication in the Results section to highlight the key factor behind this result and guide the reader to the relevant discussion (l.299).

This counter-intuitive pattern results from differences in the response of biomass pools and fluxes to repeated disturbances, as discussed in Section 4.

20) (L298) Fig. 4d: Why were no scenarios excluded (colored white) due to biomass being too low for grazing?

As mentioned in Section 2.4.1, scenarios are excluded when the average dry matter intake falls below 80% of the livestock's feed requirement. Biomass levels can be lower, but still sufficient to meet this threshold. The reasoning behind this result is discussed in Section 4 (lines 406–419) and summarized in our response to Comment 19.

21) L304:
a. Why does recently-established grazing have such a higher average dry matter intake?
b. Are these numbers for the "no burning" treatment specifically?

Thank you for your question. Yes, these values refer specifically to the no burning treatment. The higher average dry matter intake under recently-established grazing results from the fact that vegetation biomass is still relatively high at the beginning of the simulation, before the full effects of grazing disturbance accumulate. We have clarified this in the manuscript (l.304):

Under no burning conditions, the average dry matter intake is 309 g m2 for recently-established grazing and 42 g m2 for pre-established grazing. The higher intake in the recently-established scenario reflects the initially high vegetation biomass before long-term grazing effects reduce plant availability.

23) L316-317: What is this "optimum" value? Optimum for what?

Thank you for the comment. The "optimum" value refers to the soil C:N ratio considered ideal for promoting healthy nutrient cycling . We have clarified this in the revised text (l.315):

In fact, even in undisturbed scenarios, the soil in the Cerrado site is not rich in nitrogen, as indicated by a soil C:N ratio of 16.65, which is above the target value of 15 considered an optimum for maintaining nitrogen availability to plants.

25) L321: What "initial nitrogen deficit"? Deficit relative to what?

Thank you for the comment. We have clarified in the manuscript that we are referring to a soil nitrogen deficit (l.321):

However, in the recent disturbance scenario, we notice that the introduction of burning practices helps to alleviate the initial soil nitrogen deficit, decreasing the C:N ratio up to 1.6% without grazing and with frequent burning.

32) L351-352: Are you saying that both BNF and litterfall are directly attributable to the plant C and N pools? Is that because LPJmL doesn't represent asymbiotic BNF?

Thank you for pointing this out. The original sentence was indeed misleading. We intended to say that BNF and litterfall originate from the vegetation pools. In the model, both are attributed to the soil nitrogen budget: BNF is allocated to the NH_4^+ pool, while litterfall contributes to the SOM pool. We have revised the sentence accordingly (L351–352):

In the case of the soil nitrogen budget, only BNF and litterfall are directly derived from the plant carbon and nitrogen pools and are the primary input fluxes of nitrogen.

For clarification regarding BNF, LPJmL produces a crude estimate of total BNF without distinguishing between fixation mechanisms and without accounting for the energetic cost to the plant for nitrogen fixation.

35) L356:
a. This statement doesn't make sense in the context of Fig. 11, which deals with soil N only, not ecosystem N.
b. The "primarily due to minimal grazing" part of this statement is not supported by Figs. 10 or 11. Fig. 10c suggests that most N losses from the Caatinga system are due to leaching, not grazing (harvest N loss). While the harvest N bars are needed in most cases to drop the net flux below the zero line in Fig. 10c, that figure only shows the result for the Caatinga with grazing on. It can't be safely assumed that ecosystem or soil N flux would be positive without grazing, because without grazing many parts of the system are changed. The authors performed more experiments than are shown here, but if those experiments support this assertion, they should be presented somewhere and cited here.

Thank you for highlighting this inconsistency. We agree that the original statement was misleading in the context of Fig. 11. As shown in Fig. 10c, leaching is indeed the main driver of net nitrogen loss in the Caatinga system, not grazing. Furthermore, simulations without grazing also show a net nitrogen loss, indicating that grazing is not the primary cause of the negative nitrogen balance. While these additional results support our statement, we have chosen not to include them in the manuscript to maintain focus and keep the manuscript concise. However, we have revised the text to better reflect the findings shown in Fig. 10c and avoid unsupported claims (l.356) :

Even without fire practices, the ecosystem experiences a net nitrogen loss primarily due to the leaching (Fig.10 c).

37) L369-371: What drives the ratio of allocated C:N and how it changes after disturbance?

The allocation process follows a strict, non-linear scheme influenced by changes in water and nitrogen availability. We prescribe a target range for the C:N ratio in leaves and roots. Variations in water and nitrogen affect the actual allocation to ensure values remain within this prescribed C:N ratio range. At the same time, water and nitrogen availability influence leaf mass, thereby altering the leaf-to-root carbon mass ratio. Disturbances therefore do not primarily target the C:N ratio itself but rather the leaf-to-root ratio, which in turn can affect the C:N ratio. We will clarify this mechanism in the revised manuscript to make it more explicit.

47) Throughout:
a. Use of "significant" implies a statistical test when none was performed. This mostly happens in figure captions but is also present in the main text

Thank you for pointing this out. We have revised the text and figure captions to avoid the use of "significant" in contexts where no statistical test was performed, in order to prevent any confusion.

<u>Comments related to figures</u>
Redundant comments have not been reported to avoid repetition.

3) All figures except Fig. 1, or at least certain labels in those figures, seem have JPEG artifacts. In most cases these should be replaced with entirely vector-based figures (.eps or .pdf). Failing that, PNG should be used. JPEG should only be used for photos (and don't just convert JPEGs to PNG!).

We will revise all figures accordingly. Specifically we will replace current figures with vector formats (.EPS or .PDF) wherever possible.

4) The "matrix"-type figures (Figs. 4–9) need a fair amount of work:

a. All of these figures should have color bars. It should also be made obvious when subplots share a color bar.

b. There are many cells in these figures with black text on a dark background. This should be avoided, for instance by adding a white outline or "glow" around all text that overlays a non-white background.

c. Some of these seem to be true values, while others are changes relative to a baseline. This is hard to keep track of and introduces an extra mental load in interpreting them. Please consider standardizing on one or the other.

d. In some of these, white represents "excluded because of insufficient biomass for grazing," whereas in others it's burgundy. This should be standardized to burgundy (or even better for colorblind readers, black). I say this because white is confusing: In Figs. 4-5, the lightest color (yellow) is low impact, the darkest color (dark red) is high-impact, and pure white is the highest impact of all. The color scale goes light-dark-light.

e. Most of the cells in these matrices represent a "bad" impact, so it makes sense they are represented by a yellow-red color scale. However, some represent a "good" impact —e.g., some treatments in Fig. 8 showing soil N enrichment. In such cases, they should not be on the same color scale, because they are qualitatively different. Something other than yellow-red should thus be used—e.g., blues.

f. An extra column should be added to the right side of every matrix giving the results with no fire.

We appreciate the detailed suggestions and will incorporate them into the revised version. We are aware that the complexity of these figures, due to the large volume of data, can hinder readability. Improving their clarity is a priority, as it will enhance both the accessibility and the overall understanding of the paper.

We fully agree that the current mix of true values and relative changes can be difficult to follow and adds unnecessary cognitive load. Following your suggestion, we have standardized all results to be expressed as relative values, using the no burning scenario as the reference. Since the focus of the figure is on the impact of burning, we believe that expressing results as percentage changes relative to the reference scenario improves clarity and facilitates interpretation.

22) (L311) Fig. 6:
a. It'd be nice to have the site names in the figure title, as is done for similar figures.

Thank you for pointing this out. Initially, the site names were placed to the side of the figure, since Fig. 6 exceptionally displays results for two sites simultaneously. However, to improve consistency and clarity, we have now also included the site names in the figure title, in line with the formatting of similar figures.

b. C:N normalized to a percentage feels wrong, I think because it's a result of both the numerator and the denominator. Consider changing to actual values instead of percentage.

We understand the concern. Our choice to normalize C:N ratios was motivated by the need to focus on the relative impact of grazing and burning across sites with very different baseline conditions. As explained in Section 2.4.2, the C:N ratios are normalized using the reference C:N value for each site under undisturbed conditions. This approach enables meaningful comparisons of treatment effects across heterogeneous environmental contexts.

That said, we will clarify this reasoning more explicitly in the caption and/or the main text to avoid confusion.

31) (L346) Fig. 10:
a. This figure was very confusing at first. I was eventually able to understand it: The colors only represent N loss mechanisms, so the top of the bar is N inputs (as the authors mention), and then the colors go down from there, with the bottom of the bar representing the N balance. I think that last point should be explained in the caption. It is much more typical for these kinds of plots to have inputs stacking on top of the zero line and losses below, with a star or something to note the net flux.
b. And indeed, that's what you do in Fig. 11! I strongly suggest switching Fig. 10 to this format, using the same colors for deposition and BNF as in Fig. 11
c. Dark blue color label should be "Nitrification + denitrification".

Thank you for this valuable feedback. We agree that the current version of the figure can be confusing at first glance. As mentioned in our response to Reviewer 2, we are planning to revise the figure to adopt a more conventional layout.