The referee comments are upright, and our responses are in italics.

RC1: The present study describes simulations of grassland yields in the pre-Alpine region of Southern Germany under different management conditions and one drought year. The study uses the established model LDNDC together with a wealth of local and regional data and concludes that management, in particular number of cuts impacts grass yield and that drought reduces biomass production.

I found the paper to be very narrow in focus and to rely heavily on knowledge of how LDNDC works and the particulars of grassland management in Bavaria. The title and aim sound very promising and the drought impact on grass yield is critical in multiple regions of the world. However, the paper goes on to discuss aspects like number of cuts in detail, with only a fraction of the analysis focusing on drought effects.

Response: *We recognize the comment that only a fraction of the analysis is focusing on drought effects and in a revised manuscript we will strengthen the focus on this point. We are planning to determine drought indices (SPI, SPIE, or similar) per field. These will be used to extract the periods of strongest drought, which can then be contrasted to the other periods. We will also include the drought indices in the correlation analysis and hope that this approach will pin-down more clearly, which effects stem from drought. The refined analysis will also feed into the abstract. We agree that the title does not fully match the study and suggest to change it to "The dual role of management and drought on productivity: Data informed process-based field-scale modeling of a pre-Alpine grassland region".*

The narrower spatial focus of this paper was a deliberate choice to provide an in-depth analysis under actual, observed field management conditions. Such detailed data is usually not available at larger scales, which requires generalizations that can introduce considerable uncertainties. For the study region, we had access to uniquely detailed and reliable datasets. Firstly, the employed dates of cutting events stem from a remote sensing-based model, which was trained on data from the study region. This kind of data does not exist globally and to the best of our knowledge, this is the first study, where data derived from remote sensing was used to inform the grassland management of a biogeochemical model. Secondly, the soil data was derived together with the local authorities, which allowed us to simulate realistic soils with appropriate soil organic carbon stocks, whose spatial variation is not adequately adressed by national or EU/ global soil maps. We are not aware of a similar product on a larger scale. However, the quality of process-based simulations can only be high, if the input data is of high-quality, too. For instance, the effect of increasing yields with increasing soil organic carbon contents, and a strengthening of this effect under drought, could have not been extracted with a soil data base with a smaller range of soil organic carbon contents. Some effects, like the relation between yields and soil organic carbon could not be extracted with coarser soil input data. We want to emphasise that detailed inputs are required to empower process-based models.

RC1: I would be interested to see a more in depth analysis of the variation in drought impact and whether management has any impact on how affected by drought yields are.

Response: *For the first point, see the answer above. For the second point, we also find this an important topic in particular regarding management adaption in a changing climate. This is partly discussed in Sec. 3.4. The model predicts the largest mean yield decrease for 6-cut fields, followed by 4-, and 5-cut fields, whereas the more extensively managed fields show smaller absolute yield* *decreases (Fig. 6, and text below L371-375) which agrees well with experimental literature (e.g. Korell et al., 2024). We thank the referee for noting, that this point was not emphasised enough and in the revised manuscript, we are planning to deepen the analysis and discussion on this topic.*

RC1: It would also be useful to include a discussion of the generality and portability of this study, especially given that the study area must be one of the regions with the highest data availability in the world.

Response: *We fully understand the concern of the reviewer that the portability of the study is not discussed. We analysed an area of 4600 km^2 in the northern pre-Alps, which was chosen due to the exceptionally high accuracy of available input data. Even though the input data is not portable to other regions, the results are expected to hold for pre-Alpine areas in Switzerland, France, Italy, Austria, and Slovenia at comparable precipitation levels (800 - 1800mm), which are illustrated in Fig. 1, and potentially even other European mountain ranges. We expect that derived trends like increasing yields with increasing soil organic carbon content and buffering of negative impacts of drought on productivity are portable to these regions. In a revised version of the manuscript, we will include a discussion of the portability of the study and emphasise the unique quality of our input data, such that it becomes clear, that we balanced data requirements and possibilities that process-based models yield.*

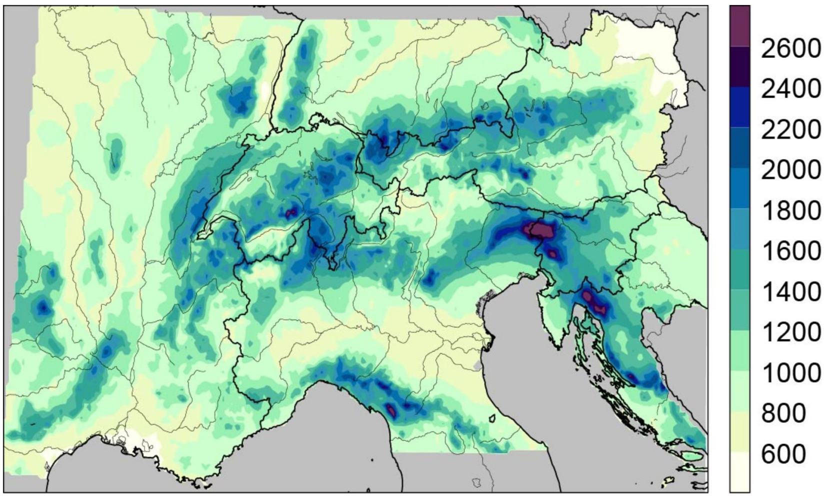

Figure 1: Mean annual precipitation sums in mm from 1971-2019 for the Alps and pre-Alps (Isotta et al., 2014). The findings from our study are expected to apply for Alpine regions with precipitation sums between 800 – 1800 mm per year.

The underlying research questions around drought and the model simulations in themselves are a good fit for Biogeosciences but in the current form, the paper would find a better form in a more agricultural or even more regional journal.

Response: *Thanks for the comment. We believe that by revising the manuscript and a more in-depth analysis of drought influenced biogeochemical impacts on grassland yields and by strengthening impacts on nitrogen cycling, we hope that the paper will fit for Biogeosciences.*

Specific comments

RC1: Abstract the text seems to mainly discuss the effects of biomass harvest, with passing mention of drought effect, contrasting to the title.

Response: *We thank the referee for this comment. In a revised version of the manuscript (including drought indices), drought, and drought-biogeochemistry impacts will also be emphasised stronger in the abstract.*

RC1: Section 31, figure 2 It would be good to have an estimate of whether the model performs well compared to observations in the dry year, to lend confidence to the further discussions

Response: *We evaluated and will include in the results section that the model validations for the dry years (2014, 2015, 2018) even result in better qualities of fit (r^2=0.84, RMSE=0.63 t ha^{-1}) than for the whole dataset.*

RC1: Section 3.4 It would help to have some sort of measure of whether differences are significant

Response: *This is the case and already mentioned in the text. All p-values, determined as described in Sec. 2.4, for yield differences between years per number of cuts are smaller than 0.01. However, significance is not a very meaningful measure in the context of large datasets (comp. Sec. 2.4), which is why we did not emphasise this point more.*

RC1: Figure captions – please extend the text to be more descriptive of that is the figures

Response: *We thank the referee for the demand on more extensive figure captions. We believe that figures are key and will extend the figure legends in a revised version.*

RC1: Section 3.5 I do not fully understand the logic behind a corelative analysis of model simulations. Surely since LDNDC is a process-based model, internal drivers can be illustrated based on model output variables and process understanding.

Response: *We fully agree that it is an interesting question, if correlative analysis of model inputs and results is necessary and meaningful, since in principle processes are included intrinsically. In complex models like LandscapeDNDC, which incorporate many partly non-linear processes on different scales, it is not possible to follow the matter fluxes continuously, in particular for many simulations. The use of correlations allows to extract, which relations arise in the dataset created through a complex interplay of many processes. These extracted direct relations capture mean behavior and are understandable and applicable within simpler empirical models. For instance, for estimations of yields based on elevation as employed in [Richner et al., 2017], or for look-up tables based on soil quality related to soil organic carbon [Bayerisches Landesamt für Landwirtschaft, 2018].*

RC1: Data availability – I believe that the Copernicus policy requires all data and code to be open

Response: *The referee is right, that the Copernicus policy requires all data and code to be open. The LandscapeDNDC source code for released versions of the model can be downloaded at the Radar4KIT database (https://doi.org/10.35097/438; Butterbach-Bahl et al., 2021). The model inputs rely on field information from the Integrated Administration and Control System, which is the basis of field locations, boarder, and management class. This data includes privacy information and thus is protected and we can not publish it. Instead, we will upload the model in- and outputs aggregated onto hexagons for individual numbers of cuts to the Radar4KIT repository. The measurements used for validation and regional evaluation will be uploaded to the Bonares repository. The regional cutting dates will soon appear on the EOC Geoservice.*

Minor comments

RC1: L50 As well as translocation experiments, there are also an increasing number of rainfall exclusion experiments which do not suffer from any of the caveats discussed here

Response: *Thank you for this information. We will read through the according literature and add information on these interesting experiments here.*

RC1: L103 this paragraph detailing previous uses of LDNDC belongs more in the introduction than the model description

Response: *Thank you for noting. We will shift and adapt L103-113 to the introduction.*

RC1: L117 a 2 year spin up seems extremely short for e.g. soil C and N stocks, what was the reasoning behind this?

Response: *The employed soilchemistry module Metr^x in LandscapeDNDC is set up to adjust soil carbon and nitrogen pool distributions during the first two years of a simulation to align with anticipated annual carbon and nitrogen gains or losses. In this study, we applied the default setting, which assumes equilibrium conditions with no larger net gains or losses. This approach minimizes inital steep gradients of carbon and nitrogen pools, allowing the short explicit spin-up phase.*

RC1: L160 what is the spatial resolution for the regional simulation?

Response: *The spatial resolution of our simulations is field-scale, i.e. for every field an individual simulation is run, compare Sec. 2.3. Field areas range from 0.006 ha to 49 ha with a mean value of 1.2 ha. We will include these values in the revised version of the manuscript.*

RC1: L161 is there a reference for this data?

Response: *We received this data from the Landesamt für Landwirtschaft in Bavaria. In previous studies (Hänsel et al., 2023), this data was referenced with "IACS., 2014. Integrated Administration and Control System as defined in Commission Implementing Regulation (EU) No 809/2014.", which is the law it is based on. We will add this reference to the manuscript.*

RC1: L181 a brief description of how cutting dates were derived would be helpful

Response: *We will add a couple of sentences answering this point: Grassland cutting dates were derived from optical satellite time series data acquired by the Sentinel-2 sensors. Within the approach, which is outlined in more detail in Reinermann et al. 2022, a thresholding rule-set is applied to the Enhanced Vegetation Index derived from the pre-processed Sentinel-2 time series per 10 m x 10 m pixel. The thresholds were calibrated with individual parcels in the Ammer region area for which detailed management information was available. The pixel-based cutting dates were aggregated to field level by using the majority vote.*

RC1: L242 why hexagons?

Response: *We chose hexagons as the unit of aggregation, since in a hexagon the distances from the edges to the center are more similar than in a square and the variation of data to be aggregated can be expected to be smaller (for instance, lower climatic gradients per aggregation unit). In other words, a hexagon is more similar to a circle than a square, but still space-filling. For further explanations, see Birch et al., 2007.*

RC1: L319 why do MAT and MAP need to be aggregated by field area? Especially the temperature

Response: *This only makes minor differences and is done for consistency, since the aggregated yields are also weighted by field area.*

RC1: Figure 6 is this averaged over all fields or averaged over all cuts?

Response: *In Fig. 6, data is averaged over all fields per number of cuts, i.e. all fields with a certain number of cuts are taken together from all fields as a subset and mean values are derived. We will clarify this in the figure caption.*

Mentioned references

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