Answer to Reviewer #1 of manuscript for GMD:

"CLM-FruitTree: A new sub-model for deciduous fruit trees in the Community Land Model (CLM5)" (Dombrowski et al.)

➢ We thank the reviewer for taking the time to read the manuscript and for providing constructive feedback on our work. In the following we are presenting our preliminary responses to the reviewer's comments. The revision and resubmission of the paper will follow once we received the reviews of the other reviewers. We hope the reviewer will find the comments and concerns addressed appropriately in the meantime.

This manuscript describes the development of a fruit-tree sub-model as part of CLM5, a well-established land and vegetation model. As pointed out by the authors, the inclusion of new agricultural vegetation types in large scale simulation models is an important advancement for understanding and quantifying their role in many biophysical earth-system processes as well as improve the representation of the agricultural sector production. Overall, the manuscript is of good scientific quality.
One limitation of the study is that it is performed on a single point for only a few years, which limits the possibility to evaluate its validity under different conditions. On the other hand, an extremely rich dataset of measurements is used to calibrate and validate the new model. This gives confidence on the representation of processes, such as GPP, NPP, Carbon allocation and crop yields.

➢ We are pleased that the reviewer recognises the quality of our scientific work and the uniqueness of the dataset in terms of range and detail of the available measurements, which has provided a unique opportunity to develop the new CLM5 sub-model CLM-FruitTree. This work focuses on the sub-model description, but we agree that the validity of CLM-FruitTree should be further tested with datasets from other geographic regions, longer time series and different orchard types. A major challenge we see here is that data sets with similar detail as the one used in this study are hardly available for orchard ecosystems at this point. Therefore, further validation and testing of CLM-FruitTree was beyond the scope of this paper and should be rather accomplished by future studies. Nonetheless, we will further stress this point in the revised manuscript.

The results are well presented with a good structure and informative figures. Yet, some aspects have not been covered, hampering full understanding of the conceptual model and the reproducibility of results:

➢ We will address the specific comments of the reviewer #1 one by one in the following.

1) One of the greatest challenges in modelling orchards is the representation of the canopy structure, which is not closed and uniform in space, as usually assumed for arable crops and for natural forest. This is a crucial aspect that affects the way radiation is intercepted by the crop canopy. In the paper, it is not described what assumptions have been made regarding radiation interception and whether changes to the CLM5 model have been necessary.

➢ Canopy structure is indeed a crucial aspect of modelling radiation interception and energy partitioning within the crop canopy. CLM5 currently is still limited to the assumption of a closed canopy structure that is uniform in space. While future developments towards integrating multi-layer schemes for canopy processes and explicit representation of the canopy to improve related processes are desirable, they could not be realized in this development, and we did not make any changes to the existing calculations of momentum, heat, and water fluxes. We adapted the *z0mr* parameter (the ratio of momentum roughness length to canopy top height) and *displar* (the ratio of displacement height to canopy top height) to account for differences to arable crops and natural forests but we also acknowledge the limitations of not representing the orchard structure more realistically in L531-534 and L585 of the manuscript. Nonetheless, we will add a sentence in the section model conceptualization to more clearly state the assumptions that were made.

2) It is not mentioned what are the structural characteristics accounted for to represent the orchard in the model. Particularly:

➢ This comment relates to comment 1) above and is thus partially explained in the answer above. In addition, we will provide the following information on structural features in the revision:

- The planting density

➢ Planting density is specified via the *stocking* parameter used also for natural forests in CLM5. This parameter is currently not part of the parameter file but we will add it to the parameter file for the revised version of the code and manuscript. Currently the *stocking* parameter together with the *taper* parameter (ratio of stem height to radius) present the very simplified allometry of trees in CLM5 and are only used for the calculation of top canopy height.

- The in-row and between-rows planting distances and the ground covered by the canopy

➢ There are no parameters defining row spacings instead the area covered by the plants is defined by leaf and stem area index in a uniform way.

- How large are seedlings transplanted from the nursery and what is their allometry at establishment (e.g. tree height, stem diameter, LAI, sapwood/heartwood partition, ...)?

➢ Tree allometry is calculated based on the parameter values used for *stocking*, *taper,* and *transplant* (defines initial leaf and dead stem biomass) resulting in an initial tree height of around 40 cm, a stem diameter of 7 mm and LAI of 0 since trees are transplanted during winter. Seedling allometry has little effect on the biomass growth and yield of the adult trees as in any case trees reach their maximum canopy height and full LAI within the first couple of years after transplanting. We assume that for most applications of the presented developments, seedling size will be of minor interest and instead the focus will be on yield, biomass growth, C turnover etc.

3) An important process of fruit-tree species is flowering, which is not explicitly represented in the CLM-FruitTree model. Although, it is clearly an acceptable simplification in this kind of model, the assumptions behind this choice (e.g. optimal pollination, compensation effects between fruit numbers and size, ...) and its implication should be presented and discussed.

➢ As recognized by the reviewer, the explicit representation of flowering is out of the scope for a development within a land surface model aiming at large scale simulations and processes at ecosystem level. Consequently, CLM-FruitTree does not produce information on fruit size or number but only on total yield. Simulations should be calibrated against observed yield by adjusting the phenological and CN allocation parameters related to fruit growth. Effects of non-optimal pollination or fruit drop later in the season are hence not captured by the model development, which could result in lower simulated inter-annual yield variability. Following the reviewer's suggestion, we will briefly present and discuss the decision to not explicitly represent flowering in the manuscript.

Below I provide further comments on specific sections, lines and figures that need improvement.

Methods

Structure

In general section 2.1 gives the motivation for developing the CLM-FruitTree, but I think it would be better structured in this form: "to simulate fruit trees we need a model that does XYZ; CLM5 with its improvement is a good base for this, indeed it includes ABC; yet, it still misses ZYX that we implement in this paper." Otherwise it is not clear why you describe those aspects of CLM5.

- We thank the reviewer for the suggestion. We will edit this section to make clear why we introduce the different vegetation types described in CLM5. We will then explain which aspects of them and to what extent they can be used to model fruit trees before stressing the limitations of the existing vegetation characterizations.

Section 2.2 is not very informative in terms of model conceptualization. Please, use this section to (1) give an overall description of what system your model describes (e.g. what kind of apple orchard, extensive / intensive), (2) explain which components of the system should the model represent well (e.g. it should be at least good at simulating average yields and carbon stocks), (3) describe the model concept, preferably referring to the diagram displayed in Fig. 1. Here it would be a good place also to define the three C pools that are mentioned also in 2.2.2 without a proper explanation.

- Thank you for this comment, we agree that this section would benefit from adding more details on the model concepts. We will provide additional information as suggested. As the three C pools are first mentioned in section 2.1, we will define them there.

Section 2.2.1: It is good to start off with phenology. Please, stick to that and do not mix phenology with growth processes. E.g. why is initial biomass mentioned in L157? Similar for L163. Maybe, put these into a paragraph at the end of 2.2.1, describing growth processes triggered by phenological events.

- Sentences in L157 and L163 will be rephrased and moved to the first paragraph of 2.2.2.

Section 2.2.3: Please, restructure the paragraph L219-232 to make clear what is common practice in the "real world" and what is implemented in the model. First explain the common practice and then what's in the model.

- We will restructure this paragraph following the suggestion of the reviewer.

Line-specific comments

L97-99: As the names of these pools appear here for the first time, the sentence is a bit confusing. I would suggest to clarify the sentence as follows, use italic for the pool names and refer to later sections for additional details: "Once a new onset growth period is initiated, C and the corresponding N fluxes occur out of a *storage* pool, which are temporarily stored into an intermediate pool (*transfer* pool) and then gradually transferred to the *display* growth pools (see section XYZ for details)."

- We will address this comment by defining the different carbon pools in section 2.1.

L100: Are there other stoichiometric relationships other then C:N ratios? If yes, the sentence is fine, otherwise please, remove stoichiometric relationships.

- The sentence will be modified as follows: "During the active growth period, C and corresponding N storage pools of the individual plant organs are replenished based on specified C:N ratios of each plant organ."

L101-102: Sounds like a repetition of L93, please merge the two.

- We believe the reviewer is referring to the sentence in L95-96. We will shorten the sentence by removing "between different plant and litter pools." to avoid any repetition.

L122: Unclear whether the management options are related to phenology management (e.g. choice of cultivar?) or to other management practices somewhat connected to phenology (e.g. pruning?).

- For the sake of greater clarity, we will amend the sentence as follows: "we introduced a new phenology subroutine including triggers for seasonal orchard management practices"

L123-124: "were modified" is too vague. As you don't have space here to go into details, I'd suggest to be brief but explanatory, e.g. "CN fluxes and allocation were modified to fit ....".

- The sentence will be edited as follows: "the CN allocation module as well as associated modules (including C and N state and flux updates, vegetation structure, and respiration) were modified to reproduce the growth dynamics of fruit trees."

L124-128: These are very technical details and not so much part of the model conceptualization. I wonder whether it would be possible to make a separate section on "technical implementation" to describe these.

- We will rename the paragraph "Model conceptualization and technical implementation". In this way we will discuss the used modelling concepts and at the same time briefly explain their technical implementation where necessary to avoid repetition and a separate paragraph.

L135-136: This seems quite long for modern orchards. What kind of orchards are you simulating? Intensive / extensive, low / high density, what are the assumptions on the rootstock?

- The lifespan can be adjusted to any value as desired by the user. The given years are indeed on the high end for organic or semi-extensive system while intensive orchards typically have shorter lifespans of around 15 years. To avoid confusion, we will modify the sentence to "Once planted, the orchard remains productive according to a user-defined lifespan depending on production system, typically 15-20 years for intensive systems and up to 30 years for extensive systems" and will provide a reference. There are no specific assumptions made on the rootstock but the effect of different root stocks in terms of tree height and rooting depth can be set by the user via the respective parameters (*ztopmx* and *root_dmx*)

L158: Apple growth or apple-tree growth?

- Tree growth is meant, we will correct this.

L163: how large is the portion of C transferred?

- The transferred portion is 0.5 based on the assumption that resources are partially mobilized to support growth of the new season but lacking more specific knowledge on that fraction. This is the default fraction used by CLM5 in the seasonal deciduous trees algorithm.

L164: Please, provide a reference or justification for the 50 days assumption.

- This parameter was calibrated based on the biomass measurements and the estimate by Zanotelli et al. 2013 that apple trees use stored carbohydrates in the first two months after budburst. We will add this information.

L165-167: From this description ("fruit starts 4-5 w after bud break", "leaf senescence occurs after harvest") it does not seem that leaves and fruits development are independent from each other.

- Independent here meaning that they can evolve in parallel as opposed to the standard crop module were grain fill starts once leaf area development is finished. We will reformulate this to avoid confusion.

L186: Shouldn't "except for fruits where all allocated C is assigned to the displayed pool" be part of the previous sentence?

- We will change the sentence as follows: "The remainder is allocated to the displayed C pools while for fruits all allocated C is assigned to the displayed pool. "

L199-200: Allocation to fine roots and stem decline, not the root and stem pool themselves, right?

- Yes indeed, we will insert "allocation" in the sentence.

L210: Please, expand a bit on the N retranslocation strategy, not just by referring to Lawrence et al., 2018. Doesn't this belong to 2.2.2 as it refers to N allocation. Then you could call section 2.2.3 simply "Representation of management practices" and include here details of all managements, including the assumed orchard design (planting densities, raw arrangement, training system).

- We will move N retranslocation to section 2.2.2 as suggested by the reviewer and add some more detail: "The N retranslocation algorithm removes N from the falling litter based on leaf and litter CN ratios and the available C to pay for the extraction of N from increasingly more recalcitrant litter pools."

L220: What do you mean by "dead stem"? Usually pruning is meant to remove living branches. Might be that CLM does not explicitly distinguish stem and later branches. Yet, more explanations are needed here to justify the implemented pruning routine.

- CLM5 converts all live stem biomass to dead stem biomass at the end of a growing season to account for reduced maintenance cost of different tissue ages. In fact, no maintenance respiration is assumed for dead woody tissue. As such, the effect of the pruning routine is solely on the carbon pools while not affecting maintenance costs of the trees. We will add an explanation of this in section 2.2.2 upon first mention of the dead stem.

L313: for clarity, X and deltaX also need to be defined.

- We will add X and deltaX in the description of variables.

Results and Discussion

Figures

Fig. 3: To improve readability, I suggest to name the parameters with their extended names and the short name in parenthesis, e.g. gross primary production (GPP), directly in the plot and not in the caption.

- We thank the reviewer for the suggestion. We tried both versions of the figure but believe the abbreviations used are common enough to be understood without having to use the full name which would make the figure too crowded.

Fig. 5: It is not clear whether the x-axis ticks refer to the beginning/midday/end of the months. Moreover, more ticks would help reading the timing of events, e.g. when is full canopy development reached.

- We will insert additional ticks and improve the clarity of the figure in such way:

Fig. 6: According to Zanotelli et al., 2019 (section 2.1), yields in 2015 has been 63 t ha-1. Please, double check.

- We will double check this number to clarify if there has been a mistake.

Line-specific comments

L368-370: why "primarily". Isn't it all allocated to those organs? In the methods it is stated that storage Carbon is used for growth of all organs except fruits in the first 50 days after bud breaks. Moreover, from Fig.4 it looks like growth is supported by storages way beyond early May, rather until early June. When the fruit curve is already taking off.

- Yes correct, we will remove "primarily" as it is indeed misleading. Storage growth continues until early May only (it is not equivalent to the reaching of maximum LAI). The ticks refer to the start of the month, which may be the reason for the confusion. We will adapt the figure for more clarity.

L372: In Fig. 4, leaf biomass seems to reach the plateau earlier, in June. The peak in July better refers to observations, correct?

- Thanks for pointing this out, we will replace this by "mid June" and clarify that this refers to the simulated values.

L390: for clarity, replace "light pruning" with "a lighter pruning compared to the previous year" or similar. Moreover, if such lighter pruning happens on-field every second year, it should not sound like it was an extraordinary event in 2011 that cannot be captured by the model, but rather a flexibility in management that is not well represented in the model. If the model with fixed management "sees" an alternation of "good" and "bad" years, it could mean that it represents processes well, and it has a too simplified management that leaves room for improvement.

- We'll replace as suggested. To respond to the reviewer comment: The described practice is performed according to the farmer's assessment and does not follow a regular frequency (i.e. every second year). As such, the pruning remains a dynamic and somewhat subjective assessment of the farmer and information on the amount of pruning is usually not available. In addition, other apple varieties or types of deciduous fruit trees do not exhibit such behaviour which was another reason to consider the pruning amount as a fixed proportion of seasonal stem growth. However, further development may be considered in the future as the model is tested and applied more extensively.

L407-409: Not clear. Usually management should aim at reducing yield variability for both arable and perennial crops, e.g. irrigation to reduce precipitation variability, pruning to reduce alternate bearing of fruit trees, etc.

- We thank the reviewer for this comment. Indeed, the aim of field management is usually to reduce yield variability while poor management such as insufficient pruning or fruit thinning can result in undesired yield variability. More importantly however, yield variability is caused by the complex interaction of environmental conditions and tree physiological processes as well as small-scale heterogeneities in soil and trees. We will correct this in the manuscript.

L438: what is indicated in parenthesis? Standard deviation, range, ...

- Numbers in brackets represent net ecosystem exchange (NEE) as stated at the start of the sentence in L438 “Observed yearly sums of GPP (NEE) were 1.60 (-0.49),[…]”.

L457-463: This paragraph is unclear and hard to follow. Please, report measured values along with observed values and vice versa. E.g. in L457, how much is Rs and its share in Reco for the simulations? Please, move “In contrast, simulated Reco for the same year [...]” of L459 right after “[...] measurements within the orchard (total soil respiration).” in L458.

- We will restructure the paragraph as follows: “Zanotelli et al. (2013) measured a total R_s of 801±95 gC m^{-2} in 2010 contributing around 90 % to R_{eco}, based on soil chamber measurements within the orchard (total soil respiration). The comparison with parallel measurements in a trenched plot produced a high ratio R_h/R_s of 0.77 for the apple orchard. In contrast, simulated R_s was 510 gC m^{-2} contributing merely 45 % to R_{eco} for the same year with a ratio R_h/R_s of 0.87. Simulated R_{eco} was instead dominated by autotrophic respiration (R_a) due to high C costs for maintenance, mainly of leaf biomass (data not shown). Other studies found that R_s contributed 56-67 % to R_{eco} in irrigated citrus orchards of different ages (Martin-Gorriz et al., 2020) and >60 % in forest ecosystems where the magnitude of ecosystem fluxes is generally comparable to orchards (Lasslop et al., 2012; Zanotelli et al., 2013).“

L472: The representation of the different components of respiration in CLM should be explained in the methods, as this is one of the metrics to evaluate the new model implementation.

- We will include a short explanation of respiration components in CLM5 in section 2.1 of the methodology.

L462 & L478: It is not clear why citrus orchards should be a valid reference also for apple orchards. The discussion needs to be improved, bringing more references (e.g. on more tree species) if existing or justifying why citrus trees can be a good reference

- We thank the reviewer for the comment. We use citrus orchards along with other orchards such as olive (L465) as well as natural vegetation (L462) for comparison to the studied apple orchard for the lack of existing studies of respiration components in apple orchards while citrus and olive orchards are somewhat better studied. Generally, different types of orchards share common management practices such as use of heavy machinery, irrigation, fertilization, tree pruning, and mulching that have a strong influence on soil respiration components. Furthermore, structural similarities (planting in tree rows) and the fate of carbon (e.g. storage in woody organs, allocation to fruit) are other common features of different types of orchards. As such we believe it is reasonable to use them for comparison especially since we refer to relative contribution of R_s to R_{eco} and not to absolute values of respiration that may indeed show more pronounced differences between species. To strengthen the discussion, we will include some of the above made arguments and other tree species (if further literature is available) in the manuscript.

L536: In the figure soil moisture (SM) is called soil water content (SWC). Please, be consisent.

- We will use soil moisture (SM) throughout the manuscript and thus adapt the figure accordingly.