Response to Anonymous Referee #2

Thanks for your comments and suggestions. We will revise this paper according to your review comments. Below are our responses and plan for revision. Your comments are in italics, and our responses are in roman.

This study presents a modeling comparison where a single model was altered with fixed allocation and competition-driven allocation scheme along a nitrogen availability gradient and under ambient and elevated CO_2. The competition scheme that the author considered are nutrient availability and light availability. The authors found that competition-driven allocation scheme predicted different fractional allocation to fine root and wood as compared to fixed-allocation scheme. While the results are generally supported by their study, I do have several issues that I would like to bring to author's attention.

I realized the terms "fixed allocation scheme" is really confusing from reviewers' comments. It's a "fixed scheme" of allocation, while "allocation" is flexible. We will change to "single vs. multiple" in the revised version.

Major comments:

It appears that the allocation assumptions made in L 254 – 256 are key to their predicted results. In particular, it appears to me that the exact order of ***step 1 and step 2*** *may have a profound effect on the competition dynamics. I wonder what will happen if plant prioritize NSC allocation to leaf and root first, and chuck the remaining C to wood next? In the current text, I think the author did not provide sufficient discussion or justification to these potentially fundamental assumptions. Moreover, what happen if the extra C under step 4 is respired rather than allocated to wood? This could potentially match with some existing model treatment with the extra C, which deserves some discussion.*

Our description of allocation scheme is confusing, and leads to misunderstanding of the simulation experiments. We used four steps to describe the technical implementation of the ideas of the allocation model in the codes. However, it turns out this description failed to convey the major principles of the allocation scheme in our model.

In our model, the carbon assimilated by leaves via photosynthesis enters into the non-structural carbon (NSC) pool first and then is used for respiration, growth, and reproduction. The nitrogen absorbed by roots enters into the non-structural nitrogen (NSN) pool and then is allocated to plant pools (*i.e.*, leaves, fine roots, seeds, and sapwood) following plant growth. The partitioning of carbon and nitrogen into the plant pools is constrained by allometric equations, targets of leaves and fine roots, and the C:N ratios of these plant pools. The plant growth (and therefore allocation) is simulated at two steps: 1) calculating the amount of carbon and nitrogen that will be used for plant growth at this time step (which can be hourly, daily, weekly, etc.); 2) allocating the available carbon and nitrogen to leaves, fine roots, seeds, and sapwood following rules of first principles. This allocation scheme is robust and has been used in many Perfect Plasticity Approximation model-based studies. We let the plant growth follow the rules below as they are in the first version (Weng et al. 2015, Biogeoscieces. carbon only model) and second version of LM3-PPA (Weng et al. 2017, Global Change Biology. carbon and nitrogen):

1. Plants maintain their leaves and fine roots as close as possible to their targets as defined by allometry equations during the growing season (i.e., leaf and fine roots priority over stems)
2. The ratio of fine root area to leaf area is constant (pipe model) when there is no disturbance to abruptly change leaves and fine roots.
3. Plants must keep some carbon storage (i.e., NSC) for respiration (i.e., they don't suicide by using up their NSC in tissue growth).
4. C:N ratios of plant tissues must be close to their target C:N ratios, though they can have daily variations due to numerical issues in matching carbon and nitrogen allocation in daily growth.
5. Plants are able to use available carbon and nitrogen in the most efficient way from the perspective of competition.

Following these rules, our model numerically calculates the amount of carbon and nitrogen that are available for growth (i.e., building new tissues) at a daily time step. Basically, the available NSC (G_C) is the summation of a small fraction (f_2) of the total NSC in an individual plant and the differences between the targets of leaf and fine roots and their current biomass capped by a larger fraction (f_1) of NSC (Eq. 1.1). The available NSN (G_N) is analogous to that of the NSC and meets approximately the stoichiometrical requirement of plant tissues (Eq. 1.2).

$$G_C = \min\left(f_1 NSC, f_2 NSC + L^* + FR^* - L - FR\right) \qquad \text{(Eq. 1.1)}$$

$$G_N = \min\left(f_3 NSN, f_4 NSN + N_L^* + N_{FR}^* - N_L - N_{FR}\right) \qquad \text{(Eq. 1.2)}$$

where L^* and FR^* are the targets of leaves and fine roots, respectively; L and FR are current leaf and fine roots biomass, respectively; N_L^* and N_{FR}^* are nitrogen of leaves and fine roots at their targets according to their default C:N ratios. The parameter f_1 gives the daily availability of NSC during periods of leaf flush at the beginning of a growing season and f_2 for normal growth of stems after plant leaves and fine roots approach their targets. Usually, parameter f_1 is much larger than f_2. We let f_1=0.05 and f_2= 1/(365x3) in this study. The parameter f_2 is used to keep a certain amount of NSC. Likewise, the parameters f_3 and f_4 are defined the same way as f_1 and f_2. We let f_3=f_1 and f_4=f_2 for convenience in this study. Compared to carbon availability, nitrogen availability is relatively stable because SOM cannot vary wildly from day to day. Plants thus always have a stable supply of nitrogen from these SOM. The mean nitrogen available for growth (G_N) is actually equal to mean daily mineralization rate. The parameters f_3 and f_4 are only used to smooth nitrogen supply.

The allocation of the available NSC (G_C) to wood (G_W), leaves (G_L), fine roots (G_{FR}), and seeds (G_F) is following the equations below (Eqs. 2). This allocation scheme coordinates the supply of carbon and nitrogen for growth by adjusting the allocation between high-nitrogen tissues and low-nitrogen tissues to maximize leaves and fine roots growth (G_L and G_{FR}, respectively) to maximize nitrogen usage at given nitrogen supply (i.e., G_N) and keep the tissues at their default C:N ratios.

$$G_C = G_W + G_L + G_{FR} + G_F \qquad \text{(Eq. 2.1)}$$

$$G_L + G_{FR} = Min\begin{bmatrix}[L^* + FR^* - L - FR], \\ (1 - f_{W,min})\ G_C\end{bmatrix} \cdot r_{D/S} \qquad \text{(Eq. 2.2)}$$

$$G_F = v[G_C(t) \cdot r_{D/S} - (G_L + G_{FR})] \qquad \text{(Eq. 2.3)}$$

$$G_W = \left(1 - v \cdot r_{D/S}\right)G_C - (1 - v)(G_L + G_{FR}) \qquad \text{(Eq. 2.4)}$$

$$\frac{(FR+G_{FR})SRA}{(L+G_L)/LMA} = \varphi_{RL} \qquad \text{(Eq. 2.5)}$$

$$\frac{G_L}{CN_L} + \frac{G_{FR}}{CN_{FR}} + \frac{G_F}{CN_F} + \frac{G_W}{CN_W} \leq G_N \qquad \text{(Eq. 2.6)}$$

$$L + G_L \leq L^* \qquad \text{(Eq. 2.7)}$$

$$FR + G_{FR} \leq FR^* \qquad \text{(Eq. 2.8)}$$

where, $r_{D/S}$ is a nitrogen-limited allocation factor to be solved numerically each step; $f_{W,min}$ is the minimum fraction of G_C for stems (0.15 in this study); v is the fraction of carbon for seeds (0.1 in this study); CN_L, CN_{FR}, CN_F, and CN_W are the default C:N ratios of leaves, fine roots, seeds, and wood (including sapwood), respectively. Parameter $r_{D/S}$ ranges from 0 (highest nitrogen limitation; no nitrogen for leaves, fine roots, and seeds at this step) to 1 (nitrogen is sufficient for all tissues).

The allocation scheme itself is flexible and can change with environment even with one fixed scheme of allocation (i.e., fixed φ_{RL}) because of variable $r_{D/S}$. The key step in solving this set of equations is to solve $r_{D/S}$ in each growth step (daily in this model). This parameter changes with relative nitrogen availability. When there is no nitrogen limitation, $r_{D/S}$ equals to 1 and the allocation follows the conditions defined by Eqs. 2.1~2.5 (carbon only model). When $r_{D/S}$ equals to 0, G_N does not meet the nitrogen demand even if all the G_C is allocated to wood tissues and we have to return the excessive carbon to the NSC pool (this is a very rare case because of low carbon input long before $r_{D/S}$ approaches to 0 due to nitrogen limitation, though our codes must be able to deal with all possible cases.). When $r_{D/S}$ is in between ($0< r_{D/S}<1$), the leaves and fine roots cannot reach to their targets after this step of growth (i.e., plants maintain a low LAI in low nitrogen environments). At low nitrogen availability, the parameter $r_{D/S}$ keeps a low LAI, a relatively constant NPP/GPP ratio, and a stable NSC for each single PFT. The low LAI reduces carbon supply, and therefore reduces nitrogen demand for plant growth, making $r_{D/S}$ larger than zero.

Overall, this is a flexible allocation scheme and still follows the major assumptions in the previous versions of LM3-PPA (Weng, et al., 2015, 2017). It prioritizes the allocation to leaves and fine roots, maintains a minimum growth rate of stems, keeps the constant area ratio of fine roots to leaves, and optimizes resource usage by relocating carbon and nitrogen to wood tissues when nitrogen is not sufficient for full growth of leaves and fine roots. In normal growth, for each time step, leaves and fine roots get ($L^* + FR^* - L - FR$), stems $(1\text{-}v)f_2$NSC, and seeds vf_2NSC. In the early days of a growing season when leaves are much lower than its target, leaves and fine roots get a large portion of G_C (maximum is 0.85 in this study, $1\text{-}f_{W,min}$). When nitrogen is limited, leaves and fine roots are lower than their targets, reducing photosynthesis and carbon supply. So, this allocation scheme will not result in over-growth of stems because of the reduced leaves at nitrogen limitation.

Based on these allocation rules, the mean of allocations of carbon and nitrogen to leaves, fine roots, and wood over a growing season are governed by the targets for the leaf area per unit crown area (i.e., crown leaf area index, l^*) and fine root area per unit leaf area (φ_{RL}). Since the crown leaf area index, l^*, is fixed in this study, φ_{RL} is the key parameter determining the relative allocation of carbon to fine roots and stems. A high φ_{RL} means a high relative allocation to fine roots and therefore low relative allocation to stems, and *vice versa*.

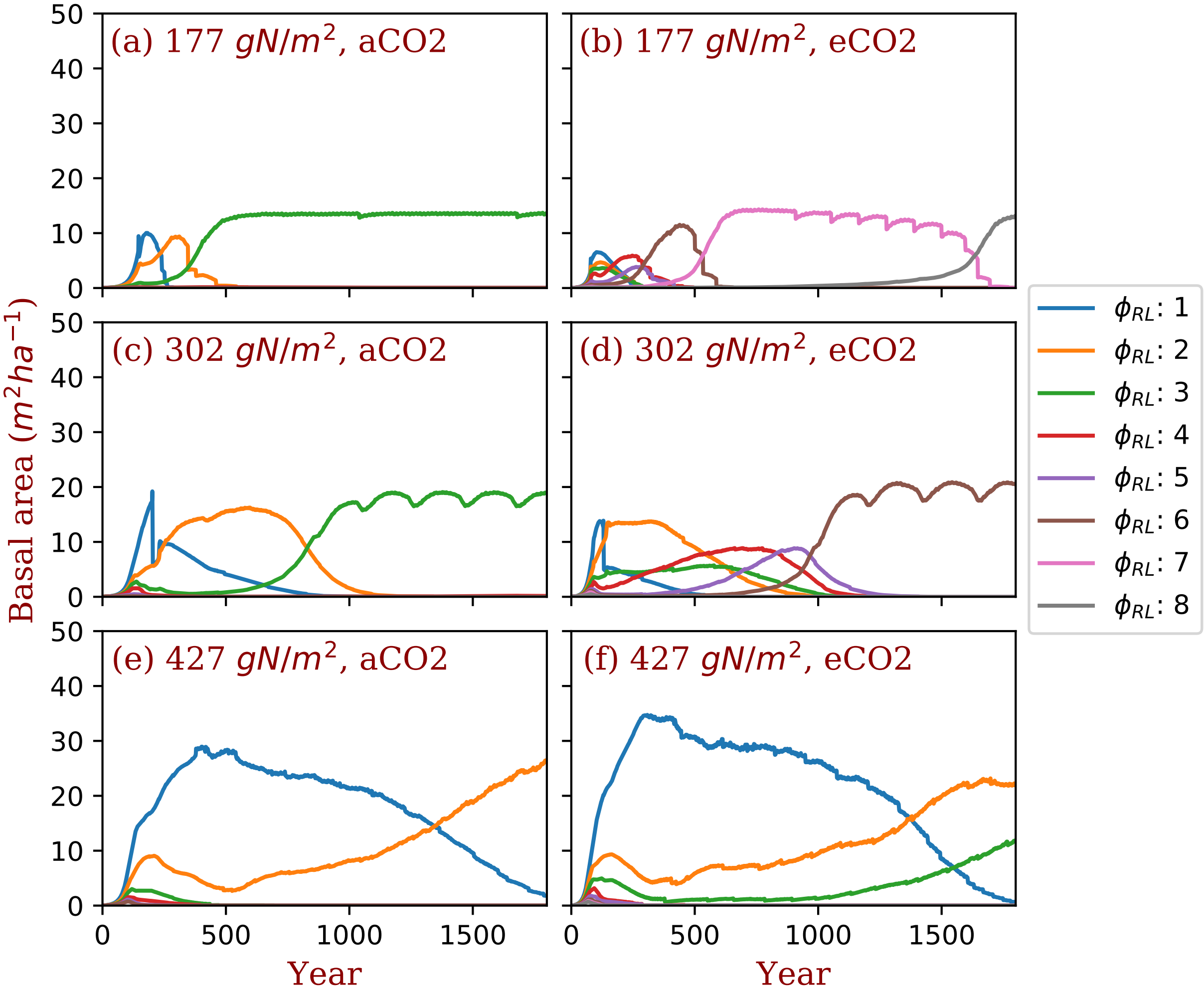
The parameter $f_{\mathrm{W,min}}$ quantifies the priority of leaves and fine roots allocation. Since allocation ratios to stems are around 0.4~0.7 in temperate forests, with a value of 0.15, it does not affect the overall allocation ratios of carbon among leaves, fine roots, and stems, and still keep trunk grow in bad years, though at a very low rate. A small $f_{\mathrm{W,min}}$ can maintain a relatively stable growth rate of tree trunk. If we let $f_{\mathrm{W,min}} = 0$ (i.e., completely leaf-fine root growth priority), trees would have unreasonably high inter-annual variation of trunk growth because leaf and fine root growth would use all carbon for approaching to their targets and leave nothing for stems in bad years.

Furthermore, while the results indicate a reversed fractional allocation pattern to fine- root and wood under competition-driven allocation scheme, there is no "data" to actually prove that this new allocation scheme is an improvement to the fixed allocation scheme. Many models already consider "dynamic" allocation based on nutrient avail- ability and water, but the author did not make any comparison against those model behaviors. I'd suggest the authors at least to bridge their modeling results with some observations to make a more convincing argument that their scheme has some advantages.

We will synthesize the data from FACE experiments and compare our results with other models.

Moreover, the author highlighted that competition for light and nutrient drives successional dynamics (e.g. L 46, 83, 105-107, etc.), which left me with the impression that successional dynamics is a key component of the paper. But in fact, it surprises me that the authors only included results on successional dynamics in the supplementary materials, and there's little discussion around this topic. I'd suggest tightening up Figure S4 and S5, and move them into the main text, with more thorough discussions around them.

We will add a succession pattern figure (below) into the paper.



Minor comments:

L 24-26: question: does this mean fixed allocation performs similarly in predicted NPP when compared to those based on competitive-allocation strategy? So the change in allocation pattern does not result in any changes in predicted NPP?

Yes, though NPP changes a little bit. Changes in allocation pattern mainly affect the relative allocation between stems and fine roots. Leaves are similar at the same nitrogen level.

L35-36. It's a bit unclear what the author trying to illustrate here.

We will rephrase this sentence.

L38: "ecosystem-level predictions" of what? You indicated earlier that the predicted NPP was similar, right?

Yes, it's ecosystem carbon dynamics. We will clarify it.

L230. The symbol φ_{RL} was described here, which appears to be too late. Suggest to define it in its first appearance.

We have moved it to the equation where it is used first time and reorganized this section.

Figure 2. The author showed how competition runs compared differently to the fixed allocation runs, based on φRL =4. Since you are talking about succession and competition, it remains unclear what is the community response?

We will add the successional figures (above in response to major comments).

Figure 3. Missing unit on y-axis.

We will replace it with the new figure below: