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Interactive comment on "C allocation among fine roots, above-, and belowground wood in a deciduous forest and its implication to ecosystem C cycling: a modelling analysis" *by* M. Campioli et al.

M. Campioli et al.

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We can summarize the critics of the reviewer in three general points: (1) description, testing and explanation of the model are partially missing, (2) some of the terminology and citations are not appropriate, and (3) the model has limitations in scope. We carefully addressed these critics in the new version of the manuscript. Specific answers are listed below. However, we would like to add first a general answer to the most important critic risen by the reviewer, that is the model limitation (point 3). The C allocation dynamics is very complex because it is the result of all tree processes related to maintenance, growth and storage of C. The few forest C cycle models considering

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C allocation are empirical. Our model represents a first process oriented approach to simulate C allocation in a deciduous forest. Because the study focuses on the non-leafy compartments and on a 6 years simulation period (model time step: 30 minutes - 24 hours), we simplified the modelling approach by (i) simulating the canopy growth in a rather descriptive way, (ii) representing most of the phenological stages with a fixed duration and (iii) overlooking the processes relevant at longer time scale (e.g. tree competition, tree aging, wood turnover). A model is a rationalisation of a real system and, of course, simplifications can not be avoided. However, if the bases are sound, further research can be inspired an increase the level of detail and accuracy of the simulations. In general, we believe our selection of processes to be described and the level of complexity used are appropriate and suited to the study objectives.

R(1) The new model is not adequately described. Not all equations are given the processes, and where they are (in Appendix A), the logic behind them is not explained. In many cases, it is completely unclear how a certain process was represented in the model. For example, about fine root growth the authors note that "It depends on specific flush rates, current standing biomass, root-leaf ratio, and annual leaf biomass maximum".

A We provided a more detailed description of the model in the new version of the manuscript: (1) We made a clearer division between description of the allocation model (CAF) and the canopy model (FORUG). For instance, the leaf phenology processes as budburst and leaf senescence are now reported in the section describing FORUG. Moreover, two appendixes are now present: Appendix A, which presents the equations of CAF and Appendix B, which presents the new equations of FORUG. (2) We provided more information about the logic behind the simulation of the various processes and equations are now meticulously cited in the text. Many improvements were done. For example, see description of simulation of fine root growth (P7, L18-29), of sink hierarchy (P8, L9-22) and of budburst and leaf yellowing (P10, L8-14). (3) Equations were added for all the processes described (note that the numbers of equations increased

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from 16 in previous version to 37 in the current version). In summary, we increased clarity in structure, extended the description and added more equations. On the other hand, we kept the concise form required for a scientific paper.

R It is also not clear to me how this model can both incorporate sink hierarchy as well as allometric ratios (which is explained, strangely, under "growth efficiency", but without details) in determining C allocation (using allometric relations to grow compartments does not require sink hierarchy and vice-versa). A more thorough description of the model might have shed light on this.

A Our approach is based on source-sink relationships. Vegetation is divided in sources and sinks which produce and consume C and exchange C among them and with the environment. In some cases, we simplified a source-sink relationship with a growth rule (e.g. a functional balance or an allometric relationship). This when an accurate simulation of a source-sink relationship would have required the coupling with dynamics that are not modelled in this study. For example, the C flux from leaves to fine roots was computed from the leaf-fine root biomass ratio because our model does not have a soil nutrient module. Similarly, the C partitioning among stem, coarse roots and branches was derived from allometric ratios because tree aging and competition was not considered. Although these approximations reduced its mechanistic character, the model appeared to be enough flexible and able to simulate C allocation within a wide range of environmental conditions and drought stress. The combination of sink hierarchy and growth rules is common in forest models (e.g. Bossel 1996, Misson 2004) as well as proportional source-sink models nested within a sink hierarchy (e.g. Hoffmann 1995). We substituted the subheading "growth efficiency" with "biomass growth".

R (2) A number of debatable assumptions are made in the model that are not well defended. Particularly, the model uses phenological stages, each of which lasts a fixed number of days. Fine root mortality seems to only take place in the summer (only in stage 3?). Turnover seems to not take place at all in the autumn period.

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A Crucial phenological events as the onset of the growing season (budburst) and its end (leaf senescence) are modelled in a process oriented way. On the other hand, the duration of the phenological stages is indeed described as fixed number of days. We were forced to this simplification because of the lack of datasets to properly develop a fully process-based phenology module. Anyway, this simplified approach relies on sound assumptions, based on phenological observations for beech and other deciduous species (P6, L16-31). A process oriented modelling of leaf phenology will be important in further research on C allocation. We discuss this in the new version of the paper (P19, L16-27). Previous research on fine root dynamics for beech and other temperate deciduous species showed that, as fine root growth, mortality of fine roots is more intense and concentrated in the summer and decreases along the season (van Praag et al. 1988, Tierney et al. 2003). We assumed it to occur only during stage 3, which in the simulations spans from mid-late May till October. It's true that fine root mortality can sometimes proceed longer, but the impact of the autumn-winter mortality it's very likely to be negligible, particularly at annual scale. The effects of wood turnover during a relatively short period, as the 6-year period considered in this study, are negligible. For longer term predictions, modelling of branch and coarse root turnover will be of importance (branch and coarse root turnover rates of about 0.01-0.05 year-1 are often used in forest models).

R (3) It would help to cite original publications (that contain experimental data), rather than previous modelling studies (such as Bossel) or general reviews (such as Lacointe, Le Roux). For example, maintenance respiration is calculated with the method of Penning de Vries (1975), but instead a 2005 modelling study is cited.

A Whenever possible, we cited original experimental publications in the new version of the manuscript. Anyway, reference to other modelling works is important when innovative approaches are reported (Bossel 1996) or when a specific algorithm is presented for a process that can be modelled in slightly different ways (e.g. budburst based on degree-days, Dufrêne et al. 2005).

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R (4) The model is not adequately tested. A carbon allocation model would ideally be tested against biomass proportions, but only stemwood increase is shown. For this comparison, the authors note that "CAF slightly overestimated wood production in 2000 and 2004", even though overestimations were 20 and 16%, resp. (Table 3).

A We corroborated the model against all the experimental datasets available at the study site (i.e. time series of wood production, standing biomass, C reserve, growth phenology, gross assimilation and averages of aboveground wood respiration, root respiration and fine root turnover). In addition, in the new version, we compare modelled and measured values of the ratio between C partitioned to wood production and GPP to test the simulated C partitioning pattern. This test was satisfactory (errors $<15\%$). Furthermore, the low correlation between errors in simulating C partitioning to wood production and errors in simulating GPP shows that our model is not biased in a systematic way (P13, L3-10). The sentence cited by the reviewer was reformulated, skipping the word "slightly" and mentioning the errors (P13, L11-13).

R A test against GPP is really irrelevant, as many more processes (and hardly allocation) go into estimation of GPP.

A Please note that the GPP test was done not to check for the validity of the allocation model but to check whether the amount of C available prior allocation was correct. This is important to understand eventual flaws in modelling C allocation and biomass production. Moreover, a correct simulation of GPP helps to understand the overall C assimilation and allocation dynamics e.g. elucidates when limited C uptake leads to consumption of C reserve, as during a severe drought. In the new version, a correct simulation of GPP is of further relevance to test the C partitioning pattern (see above).

R Why was there no test against leaf biomass (or LAI)?

A The manuscript focuses on C allocation among aboveground wood, belowground wood, and fine roots (see objectives; P5, L12-16). Therefore, the simulation of the canopy dynamics in this study is a "tool" (rather than a "goal") to have the correct

amount of C to start the allocation procedure. This was reached by using a rather detailed but descriptive canopy growth module, driven by (given) annual input of maximum LAI. A test on leaf biomass would have not provided a real added value. In any case, preliminary tests revealed that seasonality of LAI was well reproduced (e.g. see comment 1 of Result section for Reviewer 2). As explained in the introduction, this work on C allocation among branches, stems, coarse roots and fine roots, represents the first step towards the simulation of the whole-stand C allocation dynamics (P4-5, L27-2). Future development of CAF will need process oriented simulation of leaf phenology, leaf growth and LAI dynamics (P19-20, L12-13); tests for leaf biomass and LAI will then be necessary

R How does the model predict shifts in allocation with tree size, and how does this compare to other models and/or data?

A Our model does not consider changes in C allocation due to tree aging or to the different social status of the trees. These limitations are likely to be negligible because simulations span only a relatively short period (6 years). Changes in allocation with tree aging can be implemented e.g by using age-specific parameters, whereas tree competition/social status could be accounted for e.g by dividing the stand in different tree cohorts representing each different tree social class (P20-21, L14-4).

R Does the model improve allocation estimates over a null-model, which uses fixed allocation ratios?

A We did not present such comparison. However, our study accurately shows that the C allocation pattern in a temperate deciduous forest presents interannual variability, in particular between years with various degree of drought stress. For instance, in 1999 (a wet year) the C invested in fine roots and wood was 16% and 67%, respectively, of the total C invested in biomass production, whereas these proportions were 34% and 45% in 2004 (a moderately dry year) and 14% and 52% in 2003 (a severely dry year). Empirical models with fixed allocation pattern (e.g. deriving increment in fine root

biomass from increment in wood biomass, Le Goff and Ottorini 2001) will definitely fail to simulate C allocation dynamics at interannual scale.

R (5) The allocation model is mixed with other model components, so that it not only describes purely the process of C allocation. Specifically on page 3786, line 2, the authors state that "We simulated C allocation using four modules: (i) autotrophic respiration, (ii) phenological development, (iii) assimilate allocation and biomass growth, and (iv) biomass losses". Sure, the actual predictions of the amount of C allocated to each compartment will depend on biomass losses (turnover), respiration rates, etc., but these processes are more inputs to the allocation routine than really part of it.

A This comment is related to the terminology used to define "allocation". To avoid confusion, we added a clear section about terminology based on relevant references (Sect. 2.1). Indeed, "allocation" can be considered as the outcome of many processes which ultimately involve all the internal, environmental and genetic factors that regulate plant subsistence and development (Cannell and Dewar 1994). Therefore, we used the word allocation as overarching term indicating the general flow of C from C sources (leaves) to C sinks (the other tree components). On the other hand, we used the term "partitioning" to define a flow of C from a source to a sink when the C flow refers specifically to a part of the total C available from the source (Litton et al. 2007).

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