Reviewer #1:

General Comments:

Comment #1

The present manuscript is a well written manuscript, which extensively describes the implementation of 4 bioenergy crops of the second generation into the DGVM ORCHIDEE. The methodology is comprehensively described and the module is validated as good as possible, that makes the manuscript more valuable.

Response #1

We thank the reviewer for the comments and suggestions. Please see the detailed point-by-point responses below.

Comment #2

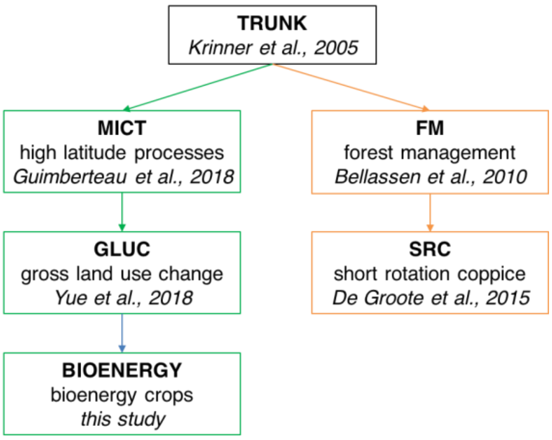
Only, it is not clear to me which ORCHIDEE model version is used here. It is not really transparent which version build on which development, as many development papers have recently been published. Could you add something like a development tree for a better understanding? How is the present version related to the version published by De Groote et al., 2015, which have already introduced a short rotation coppice poplar plantations.

Response #2

As we described on **P3L25**: "The proposed parameterizations of lignocellulosic bioenergy crops are based on an extended version of ORCHIDEE (Krinner et al., 2005) — ORCHIDEE-MICT (Guimberteau et al., 2018) which contains relevant features of gross land use change, wood harvest and forest age classes dynamics (Yue et al., 2018)."

As suggested by the reviewer, we will add a figure (reproduced below) to illustrate the origin of ORCHIDEE-BIOENERGY used in this study. The origin of the version by De Groote et al. (*2015*) is also shown in the figure, and the relationship between the two versions are explained below in details. We are aware that there are many other ORCHIDEE development papers, but they are not relevant to the bioenergy version and thus not shown.

Figure S1 The origin of ORCHIDEE-BIOENERGY version and ORCHIDEE-SRC version.



The version, ORCHIDEE-SRC by De Groote et al. (*2015*), is based on ORCHIDEE-FM, which is an old version for forest management (*Bellassen et al., 2010*). In the forest management module, stand and management characteristics, such as stand density, timing and intensity of thinning, wood removals from stand and post-thinning litter dynamics are simulated (*Bellassen ett al., 2010*). De Groote et al. (2015) further introduced short rotation coppice poplar plantations in that version and evaluated the model using data from two Belgian poplar plantation sites. However, the forest management module is not compatible with ORCHIDEE-MICT, which has the following important extension compared to ORCHIDEE-SRC / ORCHIDEE-FM.

ORCHIDEE-MICT simulates explicitly 1) gross land use change, which is important to simulate the carbon emissions from land use change in future BECCS scenarios, and 2) the age composition dynamics of woody bioenergy crops in relation to their harvest in a grid cell. The explicit spatial separation of different forest age cohorts allows a proper bookkeeping of different ages of rotation forests and tracking individually their carbon stock dynamics and areal cohorts. In addition, we aimed to introduce additional herbaceous bioenergy crops like *Miscanthus* and switchgrass as well as woody crops like eucalypt, willow and poplar in a more systematic way on the global scale (not only poplar for Europe as in ORCHIDEE-SRC).

We will add sentences to explain the relationship with the version by De Groote et al. (*2015*) on **P3L28**: "There is another ORCHIDEE version including short rotation coppice poplar plantations (ORCHIDEE-SRC, De Groote et al., 20015) based on the forest management module (*Bellassen et al., 2010*), but ORCHIDEE-SRC is more designed for studying specific coppicing processes and is evaluated using only two coppicing sites in Belgium. Although detailed forest management processes are not included in ORCHIDEE-MICT, this version includes explicit gross land use changes, i.e., the rotational transitions from other vegetation types to woody bioenergy crops and periodic clear-cut harvest of forests. These features are important to study the carbon emissions from bioenergy crop when their areas expand by converting other land use types in future BECCS scenarios. In addition, ORCHIDEE-MICT contains a bookkeeping system to track different forest age classes as separate land cohorts at a sub-grid scale (Yue et al., 2018). This functionality allows simulating the woody harvest based on rotation length tracking individually the carbon stock dynamics of different age classes of forests. In addition to the poplar plantation in Europe in ORCHIDEE-SRC (*De Groote et al., 20015*), we aimed to include herbaceous bioenergy crops like *Miscanthus* and switchgrass as well as other woody crops like eucalypt and willow in a more systematic way on the global scale."

References

Bellassen, V., Le Maire, G., Dhôte, J. F., Ciais, P. and Viovy, N.: Modelling forest management within a global vegetation model—Part 1: Model structure and general behaviour, Ecol. Modell., 221(20), 2458–2474, doi:10.1016/J.ECOLMODEL.2010.07.008, 2010.

De Groote, T., Zona, D., Broeckx, L. S., Verlinden, M. S., Luyssaert, S., Bellassen, V., Vuichard, N., Ceulemans, R., Gobin, A. and Janssens, I. A.: ORCHIDEE-SRC v1.0: an extension of the land surface model ORCHIDEE for simulating short rotation coppice poplar plantations, Geosci. Model Dev., 8(5), 1461–1471, doi:10.5194/gmd-8-1461-2015, 2015.

Guimberteau, M., Zhu, D., Maignan, F., Huang, Y., Yue, C., Dantec-Nédélec, S., Ottlé, C., Jornet-Puig, A., Bastos, A., Laurent, P., Goll, D., Bowring, S., Chang, J., Guenet, B., Tifafi, M., Peng, S., Krinner, G., Ducharne, A., Wang, F., Wang, T., Wang, X., Wang, Y., Yin, Z., Lauerwald, R., Joetzjer, E., Qiu, C., Kim, H. and Ciais, P.: ORCHIDEE-MICT (v8.4.1), a land surface model for the high latitudes: model description and validation, Geosci. Model Dev., 11(1), 121–163, doi:10.5194/gmd-11-121-2018, 2018.

Yue, C., Ciais, P., Luyssaert, S., Li, W., McGrath, M. J., Chang, J. and Peng, S.: Representing anthropogenic gross land use change, wood harvest, and forest age dynamics in a global vegetation model ORCHIDEE-MICT v8.4.2, Geosci. Model Dev., 11(1), 409–428, doi:10.5194/gmd-11-409-2018, 2018.

Comment #3

Secondly, it was not clear to me how parameters are derived. Some are derived from an observational mean, which is fine, but some I couldn't reproduce where these values come from. Is it a best guess or have you tried to match observational data, but with which method?

Response #3

As described in **Section 2.3**, we did systematic parameterization changes of carbon assimilation, allocation, phenology and harvest based on field measurements / observations. Some parameters have a very limited number of observations while others have substantially more. However, the samples may also be biased in terms of species or climate zones even when a great number of observations exist. So, for each parameter, we first used the observational median and performed model simulations to see if the biomass production matches the observations. If not, we slightly adjusted it again within the observational range to make the modeled values closer to observations.

We will add sentences on **P5L4** to explain this: "The number of observations for each parameter varied due to the availability of data, and the sample may also be biased in terms of different species or climate conditions. For each parameter, we collected observational values by a detailed literature survey and used the observational medians first. We then evaluated the model predictions of biomass yields using yield observations. If there is a bias, we adjusted the parameter value within the observational range to reduce the misfit between predicted and observed yields."

Specific Comments:

Comment #4

page 4, line 7: Here again, how is the implementation of poplar related of an earlier implementation from De Groote et al., 2015?

Response #4

We will add sentences to explain the relationship with ORCHIDEE-SRC by *De Groote et al.* (*2015*) (see **Response #2**).

Comment #5

page 4, line 26: "The non-harvested biomass goes to litter"-Should that be really the case? In reality you wouldn't plough or something like that to destroy roots respectively non-harvested biomass. Furthermore you would preserve root mass for a faster growth. Especially for woody plantation, growing out of the stump is a coppice management.

Response #5

We agree that it is a rather simple approach to representing the fate of non-harvested biomass in the model for the moment. As the reviewer pointed out, in reality, the root biomass of short rotation coppice poplar and willow will be preserved for growing in the next rotation. Similarly, the root of perennial grasses like *Miscanthus* will also be left for next-year growth. However, the simplistic representation of roots in land surface model (*Warren et al., 2015*), including ORCHIDEE, in particular issues with lacking root phenology and lacking nutrient cycles, calls for introduction of fundamental root processes first. The factors listed by the referee should definitely be considered in the next stage of development to represent the carbon cycle more accurately. However, as we stated in the title and in the introduction, we only aimed to model bioenergy crop yield in this paper. We will thus add sentences in Discussion to incorporate these points on **P15L2**: "In addition to the yields from aboveground biomass, the allocation of belowground biomass also needs to be modified, and the resulting soil carbon stocks need to be evaluated. In the current version, the non-harvested parts of biomass go to the litter pool after each harvest. In reality, however, stumps and coarse roots remain alive in coppicing practices of tree species like eucalypt, poplar and willow, and new shoots grow out of these stumps in the next growing season. Similarly, new shoots grow out of rhizome for perennial grasses like *Miscanthus* in the next growing season after harvest. Carbon in such live biomass compartments does not transfer to the litter or soil and thus does not contribute to soil carbon stocks. It is necessary to correct the model processes in this respect before applying this model to account for the full carbon cycle involving bioenergy plants. Meanwhile, a global observation dataset of belowground biomass and soil organic carbon for bioenergy crops would be desirable to systematically evaluate the model, but does not exists, to the best of our knowledge."

Reference

Warren, J. M., Hanson, P. J., Iversen, C. M., Kumar, J., Walker, A. P. and Wullschleger, S. D.: Root structural and functional dynamics in terrestrial biosphere models - evaluation and recommendations, New Phytol., 205(1), 59–78, doi:10.1111/nph.13034, 2015.

Comment #6

page 5, line 15: Doesn't you need the procedure again for the new implemented PFTs?

Response #6

We agree that it will be more precise to use the temperature acclimation parameters explicitly for the specific PFTs like poplar, willow and eucalypt, but these plant types are not included in the 36 plant species in Kattge and Knorr (*2007*). Therefore, we would like to keep the parameters for general PFTs and to be compatible with PFTs other than bioenergy crops.

Comment #7

page 6. line 3: It is not clear to me how the parameters are adjusted and how have you evaluated the adjusted parameters?

Response #7

We explained how these parameters are adjusted in the following paragraph on **P6L16**: "Specifically for bioenergy crop PFTs, we increased θ to 0.8 for PFT14 (eucalypt) based on Yin and Struik (2017) and to 0.84 for PFT16 (Miscanthus) based on field measurements from Dohleman and Long (2009). Light use efficiency and productivity are high for bioenergy crops (e.g. see reviews by Forrester, 2013; Heilman et al., 1996; Karp and Shield, 2008; Laurent et al., 2015; Lewandowski et al., 2003; McCalmont et al., 2017; Whitehead and Beadle, 2004; Zub and Brancourt-Hulmel, 2010), and we thus set $\alpha(LL)$ and g_0 to the maximum boundary in their ranges from Yin and Struik (2009) to favors high light use efficiency and productivity characteristic of bioenergy cultivars (Table 2)."

Please also see **Response #3** for how we adjusted and evaluated parameters in general.

Comment #8

Equation 3: Is Jmax = Jmax25? If not, for which equation you need Jmax? Or please do not confuse the reader by defining Jmax25.

Response #8

As shown on **P5L21**, J_{max25} is J_{max} at 25 °C. J_{max} is calculated from V_{cmax} and r_{JV}, and r_{JV} is a function of growing temperature. We explained it in equations (1) and (2) on **P5L6-19**.

Comment #9

page 7, line 28: To allocate only 20 percent to roots seems to me quite small, as the root turnover leads to a higher loss of root biomass. How is root turnover parametrized?

Response #9

As shown in **Fig. S1**, the 20% allocation to belowground is for trees after 20 years for default forest PFT and ca. 10 years for bioenergy trees. For young trees, the carbon allocation to root is higher (20%-80%). This is reasonable since that younger roots have higher respiration rates than the older roots (*Bouma et al., 2001; Fukuzawa et al., 2012*).

In ORCHIDEE, trees lose their fine roots as the same rate that they lose their leaves. Leaf senescence caused by meteorological conditions include cold temperatures, water limitation or both. In addition, a fraction of leaves and fine roots is lost every time step as a function of leaf age based on the fact that trees have to renew the inefficient old leaves, especially for evergreen trees. This was reported and validated in detail in Krinner et al. (*2005*). The emerging evidence of decoupled root and leaf phenology (*Warren et al., 2015*) is not yet represented in land surface models.

References

Bouma, T. J., Yanai, R. D., Elkin, A. D., Hartmond, U., Flores-Alva, D. E. and Eissenstat, D. M.: Estimating age-dependent costs and benefits of roots with contrasting life span: comparing apples and oranges, New Phytol., 150(3), 685–695, doi:10.1046/j.1469-8137.2001.00128.x, 2001.

Fukuzawa, K., Dannoura, M. and Shibata, H.: Fine root dynamics and root respiration, in Measuring roots, pp. 291–302, Springer., 2012.

Krinner, G., Viovy, N., de Noblet-Ducoudré, N., Ogée, J., Polcher, J., Friedlingstein, P., Ciais, P., Sitch, S. and Prentice, I. C.: A dynamic global vegetation model for studies of the coupled atmosphere-biosphere system, Global Biogeochem. Cycles, 19(1), doi:10.1029/2003GB002199, 2005.

Warren, J. M., Hanson, P. J., Iversen, C. M., Kumar, J., Walker, A. P. and Wullschleger, S. D.: Root structural and functional dynamics in terrestrial biosphere models - evaluation and recommendations, New Phytol., 205(1), 59–78, doi:10.1111/nph.13034, 2015.

Comment #10

page 7, line 30: I think not to account for growth out of the stump could cause a deceleration of biomass production which is not realistic, but it also causing to high carbon sequestration into the soil.

Response #10

We agree that it is important to account for the stump in the model (see **Response #5**), but we don't fully agree that "it could cause a deceleration of biomass production". We have already evaluated the biomass-age relationship from the model using multiple observation sites (**Section 3.4**). The model generally captured the growth curves from observations (some sites for total biomass of aboveground and belowground, **Figure 4 and 5**), and the model-observation difference can be largely explained by the species varieties and management (see details in **Section 3.4**) that are not explicitly implemented in the model. Therefore, not accounting for the stump growth does not necessarily lead to a deceleration of biomass production. Otherwise, we may not be able to validate the yields.

We are fully aware that the fate of belowground biomass after harvest is important to derive the full carbon cycle. We have a reserve carbon pool for leaf onset in ORCHIDEE (*Krinner et al., 2005*), and a simple approach to account for the stump is to leave some carbon in this reserve pool after harvest. We will implement this feature and evaluate the belowground and soil carbon in the next step of development, also after collecting new observation data for belowground and soil carbon of different bioenergy crops.

Comment #11

page 8, line 21: What is the reason for harvesting in winter at lower biomass harvest? Is that really nutrient recycling? I would assume that you can add nutrients in a managed system.

Response #11

Yes, it is due to the nutrient recycling and drying. It could be harvest at maximum yield, and then nutrients need to be added as the reviewer pointed out. However, fertilization increases cost, leaching and N_2O emissions and is neither cost-effective nor environmentally beneficial. In fact, it is recommended to harvest between January and March in the "Planting and Growing Miscanthus – Best Practice Guidelines" by the UK ministry of agriculture (*DEFRA, 2007*).

We will revise the sentence here to make it more clear: "In practice, harvesting of *Miscanthus* and switchgrass is usually performed in winter and early next spring after drying and nutrient recycling through leaf falling off (Lewandowski et al., 2003; Zub and Brancourt-Hulmel, 2010) which leads to a lower biomass at harvest but enhances nutrient conservation. For example, 18%-46% of the nitrogen in *Miscanthus* can be recycled through leaf falling to soil and translocation from shoots to rhizomes (Cadoux et al., 2012). Similar seasonal nitrogen dynamics were also observed for switchgrass (Heaton et al., 2009). In fact, *Miscanthus* is recommended to be harvested between January and March in practice guidelines (DEFRA, 2007). Otherwise, fertilizers have to be applied to amend the nutrient removal from harvest, which is neither cost-effective nor environment-friendly."

References

Cadoux, S., Riche, A. B., Yates, N. E. and Machet, J.-M.: Nutrient requirements of Miscanthus x giganteus: conclusions from a review of published studies, Biomass and Bioenergy, 38, 14–22, 2012.

DEFRA: Planting and Growing Miscanthus., 2007.

Heaton, E. A., Dohleman, F. G. and Long, S. P.: Seasonal nitrogen dynamics of Miscanthus × giganteus and Panicum virgatum, GCB Bioenergy, 1(4), 297–307, doi:10.1111/j.1757-1707.2009.01022.x, 2009.

Lewandowski, I., Scurlock, J. M. O., Lindvall, E. and Christou, M.: The development and current status of perennial rhizomatous grasses as energy crops in the US and Europe, Biomass and bioenergy, 25(4), 335–361, 2003.

Zub, H. W. and Brancourt-Hulmel, M.: Agronomic and physiological performances of different species of Miscanthus, a major energy crop. A review, Agron. Sustain. Dev., 30(2), 201–214, 2010.

Comment #12

page 9, line 4: But isn't it less practical to harvest in nearly each age class? The harvester could harm other trees. I would assume that plantations consist of homogeneous age classes and are harvested at a certain age. But maybe I do not understand which practise you assume here.

Response #12

Yes, plantations in the model are assumed to be homogeneous cohorts in as different patches of a model grid cell and harvested at certain age of maturity. Here, the "boundary" refers to the threshold of biomass to define age classes or cohorts in the model, not the physical boundary between different patches in reality. To avoid misleading, we will revise this sentence as: "Namely, harvesting starts from the second youngest age class, thus the age in the second youngest forest age cohort should be set up as same as the rotation length."

Comment #13

page 9, line 15: Are there "real" plantations" already or are that more experimental sites?

Response #13

We will add a sentence to clarify it here: "Most of the measurements (>90%) are based experimental trials, especially for *Miscanthus* and switchgrass."

Comment #14

page9, line 23: "Note that this dataset does not distinguish the utilization .." - But that makes a big difference.

Response #14

First, this is not a problem for *Miscanthus* and switchgrass because they are both designed for bioenergy purpose in the experimental trials. It may influence the woody crops like poplar, willow and eucalypt, but there are not a great number of studies on woody plantation for bioenergy use. Although some plantations are for timber or pulpwood, they can still provide the specific growth information for this woody crop type. We would think it is justified to use these biomass production observations to evaluate the model, considering maybe more uncertainties induced by species and genotype differences and management practices.

Comment #15

page 10, line 21: It might be better to count the harvest events.

Response #15

Because we artificially harvest 1% of the grid cell each year and re-plant immediately, after the first 5 years (the rotation length), there is always a fraction that is ready for harvest. For example, regrowth of 1st year harvest patches will reach the rotation length in the 5th year, and the 2nd year harvest patches will reach a full rotation in the 6th year… Therefore, we used the last 10 years harvested biomass, representing 10 harvested events but probably from different patches.

We will revise the sentence here to clarify it: "The harvested biomass for the last 10 years was used to calculate the median and range of the simulated yields. Note that we artificially harvest 1% of the grid cells each year, and the harvested patches will be planted immediately. After the first 5 years (one rotation length), there is always a fraction reaching a full rotation and ready for harvest. The harvest in the last 10 years thus represents 10 harvest events."

Comment #16

page 10, line 25: But this is of enormous importance if you like to estimate biomass potentials for BECCS. It is essential to balance the harvest and the soil carbon losses and the carbon needed for the establishment of a biomass plantation.

Response #16

Yes, we agree that soil carbon should be evaluated before using this model to study the full carbon cycle for BECCS. The biomass productivity is relatively isolated from other carbon pools like soil carbon in the model, so the implementation and parameterizations in this study are sufficient to simulate the biomass yields only. The soil carbon evaluation will be conducted in the next step, but it will take time and efforts to collect soil carbon data from observations for different crops. As we stated in the title and introduction, we only aimed to capture the biomass yield observations on global scale in this paper.

Comment #17

page 13, line 19: But it seems also that the model underestimates yields in dry regions. Blue rectangle tend to be more left sided for PFT15, 16, and 17.

Response #17

As suggested, we will add sentences here to point out this finding: "The strong underestimation (darker blue color) seems more aligned to the drier regions, especially for poplar and willow (PFT15, Fig. 10b)."

Comment #18

page 14, line 14: "... different carbon dynamics in litter and soil and water and energy balance can be expected." That's why you need to take for the soil carbon balance as well. This is one of the main issue I have on that manuscript.

Response #18

Please see **Response #5**, **#10** and **#16**.

Comment #19

page 15, line 2: "... global dataset of soil organic carbon for bioenergy crops to our knowledge." At least you should try to represent the carbon cycle right.

Response #19

Please see **Response #5**, **#10** and **#16**.