Reviewer #2:

General Comments:

Comment #1

Overall, this manuscript is a straightforward evaluation of a PFT parameterization in a well-established global biogeochemical model. The authors are adding parameterization of specific plants that are used in lignocellulosic biomass for biofuels. The study is motivated by need to connect a global land biogeochemical model, which typically do not have specific parameterization of biofuel crops, to Integrative Assessment Models that include extensive uses of biofuels in many scenarios for energy development.

I appreciate the authors documenting this model developing through a relatively short publication and that the parameters presented are commonly used across other global biogeochemical models. This will allow the manuscript serve as a resource for other modeling groups that add these bioenergy crops to their simulations.

Response #1

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

Comment #2

My main critique of the manuscript is that it needs more analysis and discussion of causes of the model-data mismatch, specifically the role of management in the parameterization and the observation datasets.

The authors mention that there is considerable variation many of the parameters (e.g., Page 5, line 24). Is that variation related to management? Could there be a parameterization for high intensity management (nutrient additions, irrigation, advanced genetics) and a parameterization for lower intensity management? In general, it would be useful to provide more information about the drivers of variation in the parameters for each species.

Response #2

As suggested, we will add sentences to discuss the variations of parameters related to managements on **P14L26**: "We adjusted some key parameters (e.g. V_{cmax}, J_{max} and *SLA*) related to productivity of bioenergy crops based on a collection of field measurements. We only took the medians and the ranges to validate the parameter values in the model but didn't explicitly consider the impacts of management (e.g. fertilization, species) on these parameters, neither in the model nor in the measurements. Here, we summarized some management effects on these parameters for different bioenergy crops based on measurements as follows.

1) *Miscanthus*: Wang et al. (2012) found that biomass yield of *Miscanthus* increased under nitrogen addition through elevated *SLA*, but fertilization didn't affect V_{cmax}, stomatal conductance (g_s) or the extinction coefficient (*k*). Yan et al. (2015) measured photosynthesis variables of three *Miscanthus* species in two experimental fields and found significantly higher g_s, J_{max} and V_{cmax} of *Miscanthus lutarioriparius* than *M. sacchariflorus* and *M. sinensis*.

2) Switchgrass: *SLA* differed significantly among nine cultivars of switchgrass but didn't respond significantly to water stress or nitrogen application for individual cultivar (Byrd and May II, 2000). Trócsányi et al. (2009) reported a lower *SLA* of switchgrass from the early harvest than from the late harvest. Hui et al. (2018) investigated leaf physiology of switchgrass under five precipitation treatments and found significantly higher photosynthesis rate and g_s under elevated precipitation but no significant difference under reduced precipitation compared to control plots.

3) Eucalypt: Lin et al. (2013) measured photosynthesis response of six *Eucalyptus* species to temperature and found significantly different J_{max25} and V_{cmax25} among species but non-significant differences in their ratios (J_{max25} / V_{cmax25}) and in the temperature response of J_{max} and V_{cmax}. With extra nitrogen supply, J_{max} and V_{cmax} of *Eucalyptus grandis* increased significantly, mainly associated with elevated leaf nitrogen content (Grassi et al., 2002). Sharwood et al. (2017) also found that J_{max} and V_{cmax} of *Eucalyptus globulus* were correlated with leaf nitrogen content and the ratio of J_{max}/V_{cmax} was constant under elevated CO_2 or elevated temperature, but *SLA* is influenced by different CO_2 and temperature treatments.

4) Poplar and willow: In experimental trials of three *Populus deltoides* clones and two *P. deltoides* × *P. nigra* clones, J_{max} and V_{cmax} of the former species were significantly higher than the latter hybrid despite some clonal variations (Dowell et al., 2009). Wullschleger (1993) summarized the species-specific estimates of J_{max} and V_{cmax}, and the five *Populus* species displayed large variations. In a poplar free-air CO_2 enrichment (PopFACE) experiment, *P. alba*, *P. nigra* and *P.* × *euramericana* showed significant difference of g_s but non-significant difference of J_{max} and V_{cmax} among species, while the elevated CO_2 significantly decreased J_{max} and V_{cmax} but had no influence on g_s species (Bernacchi et al., 2013). *SLA* was also found to differ significantly between *P. deltoides* × *P. nigra* family and *P. deltoides* × *P. trichocarpa* family (Marron et al., 2007). For willows, *SLA* increased significantly under fertilization and irrigation, but the magnitude of response varied among six varieties of *Salix* species (Weih and Ronnberg-Wastljung, 2007). Similarly, the response of *SLA* and g_s to nitrogen fertilization differed among three willow clones, but no significant difference of V_{cmax} was found between fertilization and control plots for all clones (Merilo et al. 2006).

In general, the values of parameters like V_{cmax}, J_{max} and *SLA* differ among different species or genotypes within each bioenergy crop type. The parameter responses to management like fertilization and irrigation also show large variations depending on the specific species. Although the effects of management on these parameters seem evident in some cases, a set of quantitative relationships that can be applied in relation to simple management operations in a global vegetation model for large scale and generalized PFT is still lacking. Expanding PFT level to species level in global vegetation models requires substantial computational resource, and more importantly, there may be not enough measured parameters of each species for all the processes implemented in the models. At this stage, therefore, using the medians and ranges across a great number of observations is a more justified and practical way to tune the parameters in the models. But more field measurements and quantitative reviews of relationships between individual parameter and individual management as well as interactions between different parameters and managements are highly needed in future research."

Reference

Bernacchi, C. J., Calfapietra, C., Davey, P. A., Wittig, V. E., Scarascia-Mugnozza, G. E., Raines, C. A. and Long, S. P.: Photosynthesis and stomatal conductance responses of poplars to free-air CO2 enrichment (PopFACE) during the first growth cycle and immediately following coppice, New Phytol., 159(3), 609–621, doi:10.1046/j.1469-8137.2003.00850.x, 2003.

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Grassi, G., Meir, P., Cromer, R., Tompkins, D. and Jarvis, P. G.: Photosynthetic parameters in seedlings of Eucalyptus grandis as affected by rate of nitrogen supply, Plant, Cell Environ., 25(12), 1677–1688, doi:10.1046/j.1365-3040.2002.00946.x, 2002.

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Marron, N., Dillen, S. Y. and Ceulemans, R.: Evaluation of leaf traits for indirect selection of high yielding poplar hybrids, Environ. Exp. Bot., 61(2), 103–116, doi:10.1016/j.envexpbot.2007.04.002, 2007.

Merilo, E., Heinsoo, K., Kull, O., Söderbergh, I., Lundmark, T. and Koppel, A.: Leaf photosynthetic properties in a willow (Salix viminalis and salix dasyclados) plantation in response to fertilization, Eur. J. For. Res., 125(2), 93–100, doi:10.1007/s10342-005-0073-7, 2006.

Sharwood, R. E., Crous, K. Y., Whitney, S. M., Ellsworth, D. S. and Ghannoum, O.: Linking photosynthesis and leaf N allocation under future elevated CO2 and climate warming in Eucalyptus globulus, J. Exp. Bot., 68(5), 1157–1167, doi:10.1093/jxb/erw484, 2017.

Trócsányi, Z. K., Fieldsend, A. F. and Wolf, D. D.: Yield and canopy characteristics of switchgrass (Panicum virgatum L.) as influenced by cutting management, Biomass and Bioenergy, 33(3), 442–448, doi:10.1016/j.biombioe.2008.08.014, 2009.

Wullschleger, S. D.: Biochemical limitations to carbon assimilation in C3 plants—a retrospective analysis of the A/Ci curves from 109 species, J. Exp. Bot., 44(5), 907–920, 1993.

Wang, D., Maughan, M. W., Sun, J., Feng, X., Miguez, F., Lee, D. and Dietze, M. C.: Impact of nitrogen allocation on growth and photosynthesis of Miscanthus (Miscanthus× giganteus), Gcb Bioenergy, 4(6), 688–697, 2012.

Weih, M. and Rönnberg-Wästjung, A.-C.: Shoot biomass growth is related to the vertical leaf nitrogen gradient in Salix canopies., Tree Physiol., 27(11), 1551–1559, doi:10.1093/treephys/27.11.1551, 2007.
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Yan, J., Zhu, C., Liu, W., Luo, F., Mi, J., Ren, Y., Li, J. and Sang, T.: High photosynthetic rate and water use efficiency of Miscanthus lutarioriparius characterize an energy crop in the semiarid temperate region, Gcb Bioenergy, 7(2), 207–218, 2015.

Comment #3

The manuscript focuses on a global analysis, rather than comparing directly to individual field studies. By averaging the studies within a grid-cell, there is considerable variation in the observations within a grid-cell (Figure 3). I assume that much of this variation can be attributed to differences in management of the bioenergy crop. For example, there are likely different levels of nutrient fertilization, irrigation, and use of specific genotypes within a grid-cell. I recommend exploring this variation more. Do the simulations compare better to yields from specific types of management? Addressing this question will help set a path for future model development that includes management practices. For example, if the simulations compare better to the nutrient fertilization treatment trials, then including nutrient limitation will potentially help improve the simulations of the biofuel. I realize that the paragraph on page 11, line 9 address this issue but I found paragraph to be weak. Can the studies not be roughly categorized by management intensity? Furthermore, the final sentence "implying the model is able to capture at least some of the observations in these grid cells" does not give much confidence that the new parameterization is actually an improvement.

Response #3

As suggested, we further categorized the observations with different managements (i.e. fertilization, irrigation and species) and added three figures and two tables (reproduced below) to show the model-observation comparison. We also fully discussed the management effects on biomass yields for each bioenergy crop based on evidence from reviews or meta-analyses (*Heaton et al., 2004; Cadoux et al., 2012; Kauter et al., 2003; De Moraes Gonçalves et al., 2004; Wang et al., 2010; Fabio et al., 2018*. See details below). We will also add sentences in the revised manuscript to incorporate these aspects:

"Management like fertilization, irrigation and species plays an important role in the biomass yields. In ORCHIDEE-MICT-BIOENERGY, nutrient limitations and management by irrigation and fertilization are not explicitly implemented. Instead, we used parameter values in the range that favors a higher productivity (Section 2.3, Fig. 1) and compared the simulated yields with the median values of all observations regardless the management (Fig. 3). We further categorized the observations into three groups (fertilization, non-fertilization or non-reported) and compared with simulated yields (Fig. S5). There is no systematic bias between simulated yields and yields at fertilized sites for all PFTs (orange dots in Fig. S5). The model seems to overestimate the yields of eucalypt at sites with non-reported information of fertilization (most gray dots above 1:1 line in Fig. S5a, Table S4) and overestimate yields of poplar and willow at sites without fertilization (green dots in Fig. S5b, Table S4). Yields at sites with non-reported fertilization information are underestimated by the model for *Miscanthus* (gray dots in Fig. S5c, Table S4) but overestimated for switchgrass (gray dots in Fig. S5d, Table S4).

We didn't group the observations based on different fertilization rates because there are large variations in the biomass response to fertilization rates. For example, in a quantitative review by Heaton et al. (2004), the relationship between yields of *Miscanthus* and nitrogen application rates were not significant. Cadoux et al. (2012) reviewed 11 studies that measured *Miscanthus* yields under fertilization, and the biomass response to nitrogen fertilization was positive in 6 of the studies but no response in the others. Similarly, some studies showed positive biomass response of poplar to nitrogen fertilization, but others didn't (Kauter et al., 2003). Eucalypt also showed variable response to fertilization while the general response was positive (De Moraes Gonçalves et al., 2004). In quantitative reviews of fertilization effects on yields of switchgrass (Wang et al., 2010) and willow (Fabio et al., 2018), the relationship between biomass yields and nitrogen fertilization rates was significantly positive but the coefficient of determination (r^2) was very low. In summary, biomass response to fertilization varied largely, and evidence from field measurements is not conclusive. More importantly, the basic soil characteristics should be taken into account in addition to the fertilization rates but unfortunately, we didn't have information of soil nutrient contents nor types, nutrient stoichiometry, rates and timing of applied fertilizers for each site from observations.

We also separated the observations based on irrigation information (irrigation, non-irrigation and non-reported) in comparison with modeled yields (Fig. S6). Both underestimation and overestimation were found for sites with different irrigation management for different PFTs. The yields of eucalypt were underestimated at sites with irrigation (blue dots in Fig. S6a, Table S4) but overestimated at sites with non-reported irrigation information (gray dots in Fig. S6a, Table S4). Compared to fertilization, not many sites reported irrigation information and the quantification of irrigation rates is more difficult. For example, some studies reported irrigation amount per year while some others only reported descriptive information like "soil moisture maintained to field capacity" or "irregular irrigation when necessary".

Comparison between simulated yields and observations for the main species of bioenergy crops is shown in Fig. S7. The model overestimated yields of *Eucalyptus urophylla* × *E. grandis*, *E. globulus* and *E. nitens* (Fig. S7a, Table S5). For poplar and willow, the model generally overestimated yields of *Populus deltoides* × *P. nigra*, *P. deltoides* but underestimated yields of *P. trichocarpa* and *Salix schwerinii* × *S. viminalis* (Fig. S7b, Table S5). There is underestimation of yields for *Miscanthus* × *giganteus* but overestimation for *Miscanthus sinensis*. In fact, the observed yields of the former are significantly higher than yields of the latter (t-test, p<0.01). Only four sites reported yields for *Panicum pretense*, and they were overestimated by the model (Fig. S7d, Table S5).
"

We also revised the final sentence as: "In addition, the error bars for most sites (67%, 73%, 74% and 64% for PFT14 to PFT17 respectively) reach the 1:1 line (Fig. 3 left panel), implying that at least some observations in these grid cells can be represented by the model.". Here we only stated that although the medians are not on the 1:1 line, some observations can be captured by the model. We didn't imply the improvement after new parameterizations here, because the improvement from the previous model version be clearly seen from **Fig. 11** and discussed in **Section 4.2**.

Fig. S5 Comparison of biomass yields simulated by ORCHIDEE-MICT-BIOENERGY and observations with or without fertilization. Orange, green and gray colors represent the median values of observations with fertilization, without fertilization or non-reported information, respectively in each grid cell. The red line indicates the 1:1 ratio line.

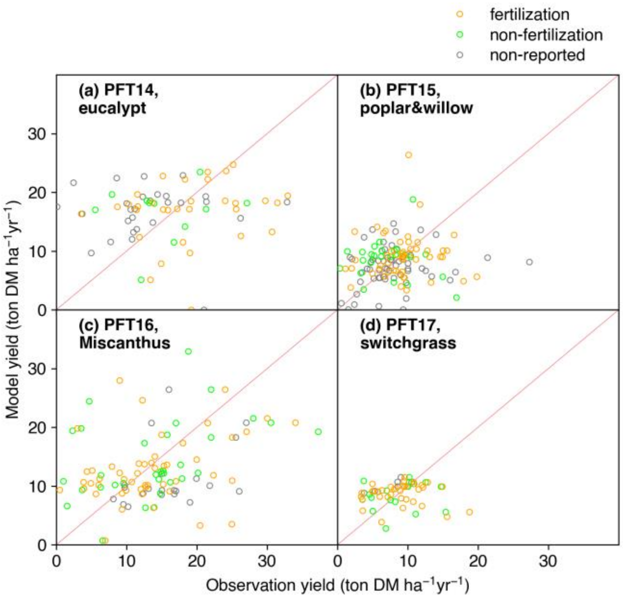

Fig. S6 Comparison of biomass yields simulated by ORCHIDEE-MICT-BIOENERGY and observations with or without irrigation. Blue, green and gray colors represent the median values of observations with irrigation, without irrigation or non-reported information, respectively in each grid cell. The red line indicates the 1:1 ratio line.

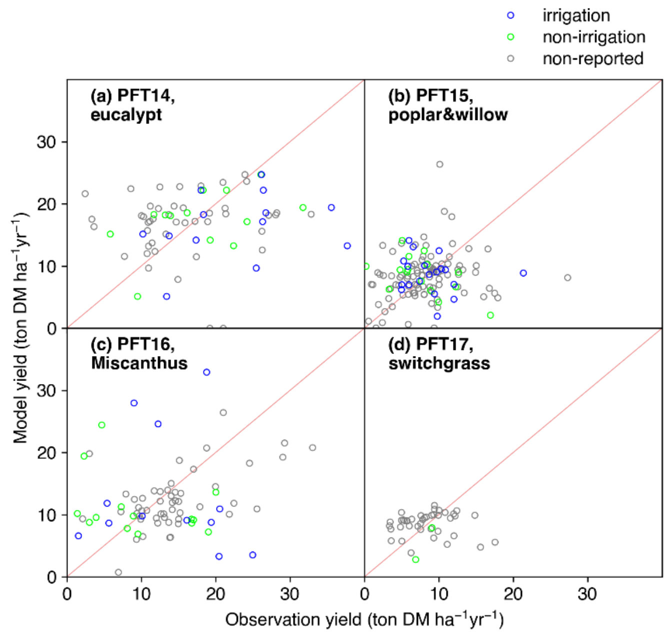

Fig. S7 Comparison of biomass yields simulated by ORCHIDEE-MICT-BIOENERGY and observations for the main species of bioenergy crops. Different colors represent the median values of observations for different species in each grid cell. The red line indicates the 1:1 ratio line.

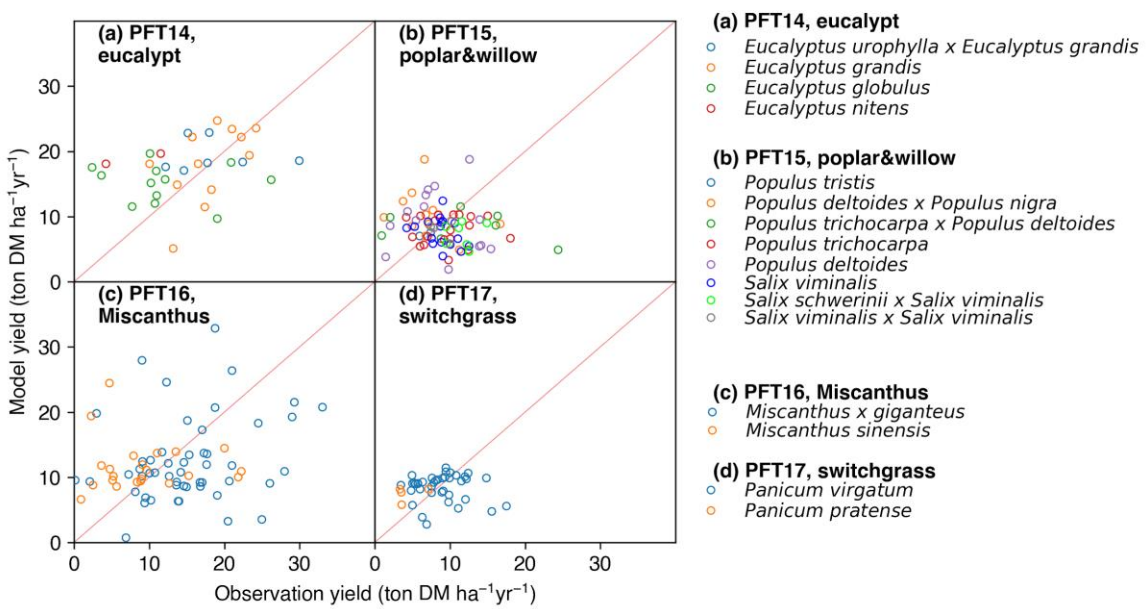

Table S4 Median and 1st and 3rd quartiles of biomass yields under different management practices from observations and the model simulation. N is number of half-degree grid cells with observations.

PFT			14, eucalypt			15, poplar & willow			16, *Miscanthus*			17, switchgrass		
			median	1st quartile	3rd quartile	median	1st quartile	3rd quartile	median	1st quartile	3rd quartile	median	1st quartile	3rd quartile
Fertilization	yes	N	32			51			50			38		
		observation	18.6	13.6	24.4	9.2	7.1	11.2	12.6	9.0	16.8	9.0	5.8	10.8
		model	17.6	15.6	18.8	9.0	6.6	10.2	11.6	9.6	14.4	9.1	8.0	9.9
	no	N	11			25			32			17		
		observation	13.9	12.4	19.4	6.3	4.7	9.5	14.7	6.5	17.7	8.2	5.0	10.8
		model	18.1	15.6	18.4	9.2	7.1	9.9	12.2	10.4	19.3	8.6	7.3	10.3
	non-reported	N	28			57			21			8		
		observation	11.9	10.1	16.3	7.1	5.1	9.8	15.0	12.4	19.0	8.5	5.6	9.1
		model	17.8	15.1	19.3	7.1	5.5	8.9	9.3	8.6	11.3	9.9	9.1	10.7
Irrigation	yes	N	13			19			12			0		
		observation	25.4	17.3	26.4	8.6	6.0	10.2	14.2	8.2	19.7			
		model	17.1	14.2	19.5	8.9	7.0	10.0	9.5	8.1	15.0			
	no	N	13			15			14			2		
		observation	18.3	13.2	22.4	7.6	5.4	9.4	8.5	4.1	16.7	8.0	7.4	8.5
		model	18.2	15.2	19.5	9.1	6.4	10.1	9.4	8.7	11.0	5.4	4.1	6.7
	non-reported	N	45	0	0	95	0	0	51	0	0	41	0	0
		observation	14.7	11.0	21.0	8.0	5.8	10.0	13.8	10.2	15.3	8.1	5.7	10.0
		model	17.6	15.2	19.3	8.5	6.2	10.0	11.3	9.7	13.8	9.1	7.7	9.9

Table S5 Median and interquartiles of biomass yields for the main species from observations and the model simulation. N is number of half-degree grid cells with observations.

	N	observation median	observation 1st quartile	observation 3rd quartile	model median	model 1st quartile	model 3rd quartile
Eucalyptus urophylla x Eucalyptus grandis	7	17.7	14.9	20.2	18.4	17.9	20.7
Eucalyptus grandis	12	17.8	15.2	21.3	18.8	14.7	22.5
Eucalyptus globulus	12	10.8	9.5	13.8	15.7	12.9	17.2
Eucalyptus nitens	2	7.9	6.0	9.7	18.9	18.5	19.3
Populus tristis	2	6.7	6.3	7.0	7.3	7.2	7.5
Populus deltoides x Populus nigra	13	6.8	4.9	7.7	9.9	8.9	11.0
Populus trichocarpa x Populus deltoides	7	11.4	5.4	16.2	8.7	6.9	10.0
Populus trichocarpa	19	9.8	6.8	11.8	7.9	6.6	10.1
Populus deltoides	14	7.5	5.7	13.5	9.5	5.5	12.9
Salix viminalis	17	8.9	7.7	10.0	8.3	5.9	9.1
Salix schwerinii x Salix viminalis	7	11.6	10.3	12.3	8.3	5.8	8.8
Salix viminalis x Salix viminalis	4	8.8	7.7	10.0	8.4	7.7	8.7
Miscanthus x giganteus	51	14.6	10.1	18.8	10.7	8.7	13.8
Miscanthus sinensis	22	8.6	4.8	12.2	10.6	9.5	13.0
Panicum virgatum	39	8.9	6.1	10.4	9.1	7.7	9.9
Panicum pratense	4	3.5	3.5	4.5	7.9	7.2	8.2

Reference

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.

De Moraes Gonçalves, J. L., Stape, J. L., Laclau, J. P., Smethurst, P. and Gava, J. L.: Silvicultural effects on the productivity and wood quality of eucalypt plantations, Forest Ecol. Manag., 193(1–2), 45–61, doi:10.1016/j.foreco.2004.01.022, 2004.

Fabio, E. S. and Smart, L. B.: Effects of nitrogen fertilization in shrub willow short rotation coppice production - a quantitative review, GCB Bioenergy, doi:10.1111/gcbb.12507, 2018.

Heaton, E., Voigt, T. and Long, S. P.: A quantitative review comparing the yields of two candidate C4 perennial biomass crops in relation to nitrogen, temperature and water, Biomass and Bioenergy, 27(1), 21–30, doi:10.1016/J.BIOMBIOE.2003.10.005, 2004.

Kauter, D., Lewandowski, I. and Claupein, W.: Quantity and quality of harvestable biomass from Populus short rotation coppice for solid fuel use - A review of the physiological basis and management influences, Biomass and Bioenergy, 24(6), 411–427, doi:10.1016/S0961-9534(02)00177-0, 2003.

Wang, D., LeBauer, D. S. and Dietze, M. C.: A quantitative review comparing the yield of switchgrass in monocultures and mixtures in relation to climate and management factors, GCB Bioenergy, 2(1), 16–25, doi:10.1111/j.1757-1707.2010.01035.x, 2010.

Comment #4

Also, these is an issue for the editors to provide input on, but the paper leans heavily on a data paper that is submitted to another unnamed journal. Therefore, a reviewer of this paper is unable to comment on the quality and applicability of the observational dataset. Should this paper be allowed to be published before that data paper is available?

Response #4

As shown on **P9L15-24**, we briefly reported information on the dataset related to this study. We already submitted the revised version of the dataset after peer-review in a data journal. If the dataset paper is accepted before this GMD manuscript, we will provide the detail reference information. The dataset will be eventually available to public and free to access (hopefully soon).

Comment #5

The spatial mapping of the model-bias is useful but it opened the question whether there are spatial differences in management that could explain the spatial variation in the mismatch.

Response #5

We agree that management would contribute to the spatial mismatch between model and observation. However, it is difficult to isolate individual management factor (e.g., species, irrigation and fertilization) or systematically evaluate the role of all these factors in driving model-observation mismatch. In addition, if we separate the spatial maps of sites with a specific management, the number of sites is limited in most cases and consequently, no spatial patterns can be observed. We thus discussed the management effects on the biases between model and observation globally as suggested by the reviewer (see **Response #3**) but didn't analyze further the regional management contributions to the spatial patterns of mismatch here.

Specific Comments:

Comment #6

The model evaluation and discussion sections blur together a bit at the edges (section 4.1 seems like a continuation of section 3). I recommend making the separation more clear.

Response #6

We will move section 4.1 from **Discussion** to **Model evaluation** section.

Comment #7

Section 3.3 says that the model-observations results generally lie around the 1:1 ratio line but doesn't provide any statistics on the fit. What is the slope and intercept from the 1:1 fit?

Response #7

We will add sentences here to report some statistics: "Although the regression between modeled and observed medians is not significant with a low r^2 value because of the overestimation and underestimation at some sites (Fig. 3 left panel), the difference between the two samples of modelled and observed yields is not significant (t-test, $p>0.17$) and the percent bias (PBIAS, defined as sum of biases divided by sum of observed values, Moriasi et al., 2007) ranges from 2% to 8% for all PFTs, implying that the global distributions of modeled and observed yields are consistent (Fig. 3 right panel). In addition, the error bars for most sites (67%, 73%, 74% and 64% for PFT14 to PFT17 respectively) reach the 1:1 line (Fig. 3 left panel), implying that at least some observations in these grid cells can be represented by the model."

Reference

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D. and Veith, T. L.: Model evaluation guidelines for systematic quantification of accuracy in watershed simulations, Trans. ASABE, 50(3), 885–900, 2007.

Comment #8

Figure 6. It is hard to see the gridcells in the subboxes. For example, box 2 in Figure 6 has lower points that are impossible to see. Can the subboxes be bigger. I also recommend adding a histogram inset that summarizing the data across grid-cells for all the similar figures (Figure 6-9)

Response #8

We will enlarge box 2 in Figure 6 and add a histogram inset in Figure 6-9 as suggested.

Comment #9

Figure 10 stated that there is a 1:1 line that is not present in the figure

Response #9

We will delete this sentence in Figure 10 caption.

Comment #10

Page 3 Line 25:Change "ORHCIDEE" to "ORCHIDEE"

Response #10

We will revise it accordingly.

Comment #11

Page 8, line 22: change 'through leaf falling off' to 'though leaf senescence'

Response #11

We will revise it accordingly.

Comment #12

Page 9 Line 8: Change "corresponding" to "corresponds".

Response #12

We will revise it accordingly.

Comment #13

Page 11 Line 27:Change "after plantation" to "after planting"

Response #13

We will revise it accordingly.

Comment #14

Page 12 Line 13:It is unclear what is meant by "because of the large spacing of plantation the trial experiment which results in . . .". Perhaps what was intended was something like: "because of the large spacing of the planting in the trial at that experimental

site, which results in . . .".

Response #14

We will revise it accordingly.

Comment #15

Page 13 Line 9: Change "US" to "the US

Response #15

We will revise it accordingly.
