Reply to Referee #2

on
BG-2015-506 Effects of climate change and land management on soil organic carbon dynamics and carbon leaching in Northwestern Europe
by M. Stergiadi, M. van der Perk, A.C.M. de Nijs, and M.F.P. Bierkens

We would like to thank the reviewer for his/her constructive comments which to improve the clarity and strengthen the analysis. The general comment about the more explicit and statistically rigorous comparison between measured values and model results is addressed in the reply to the specific comments below.

Specific Comments

1. The authors are detailed in describing CENTURY SOM and plant partitioning and turnover rates (section 2.1, p 19632 lines 22-28, p 19633 lines 1-5), but do not describe how the active pool interacts with the water submodel and clay content to generate leached carbon (CENTURY v4.0 Manual).

We have added the following paragraph at the end of section 2.1 to provide more details about the factors that control the leached DOC in the Century model:

> Part of the products from decomposition of the active pool is lost as leached DOC. The loss of leached DOC from the top 20 cm of the soil profile is positively related to the decay rate for active SOM and the water drainage rate from the soil profile up to a critical level, and is inversely related to the clay content.

2. Also, in this analysis CENTURY model simulations only extended from 0 -20cm. Therefore, modeled DOC would only be generated if water flow was deeper than the 20cm layer. This means modeled values of DOC are indicative of DOC emerging from the 20cm layer in this analysis.

This is correct. We have added a sentence in the last paragraph of section 2.2 in which we state that the DOC concentrations were calculated as annual average flow-weighted concentrations in the leachate.

3. The authors state "simulated current DOC concentrations also fall within the ranges reported in literature for agricultural and forest sites for soil depths ranging from 15 to 50 cm" (page 19641 – 19642). It is not clear if this measured/modeled comparison is meaningful, given measured depths do not match the 0-20cm of model simulations, as well as lack of information about soil texture and whether measured sites had comparable climate/precipitation/hydrology.

For a comparison of our model results with regards to soil DOC concentrations with measured values we have to rely on literature values. Direct comparison is problematic because literature values are relatively scarce, especially for the generalised soil types with various land use, which we simulated. Moreover, literature values often refer to other soil depths than 20 cm at which the Century model results refer to and are often aggregated to ranges for land use classes or soil types. Nevertheless, we agree that our initial statement in the discussion paper lacks information whether the literature values had comparable soil and climate conditions. Therefore, we added a new paragraph in which we provide a more detailed discussion how our model results compare to the reported ranges of DOC concentrations at sites in the temperate climate region of Northwestern Europe, including those from additional studies:

> The simulated current DOC concentrations are listed in Tables 6-9. Direct comparison between our model results and values reported in the literature is problematic since literature values of soil DOC concentrations observed at 20 cm depth in the systems considered in this study are scarce. Nevertheless, a few studies reported DOC concentrations for grassland, arable land, and forest sites in Northwestern Europe. Kindler et al. (2011) studied DOC concentrations and leaching at 12 sites at for soil depths ranging from 5 cm to 40 cm. They reported DOC concentration ranges of 1.9–17.1 mg L-1 for grasslands (N=4), 3.9–17.3 mg L-1 for arable land (N=3), and 7.1–43.1 mg L-1 for forests (N=5). Michalzik et al. (2001) studied the DOC concentrations in temperate forests. The three Northwestern European sites (Germany and Norway) for which DOC concentrations at depths ranging from 20 to 30 cm are reported show a range of 2.6–31.2 mg L-1. Van den Berg et al. (2012) measured DOC concentration ranges between 10.2 and 46.1 mg L-1 for forests (N=11) and between 2.5 and 29.5 mg L-1 for grasslands (N=18) in UK soils at sampling depths between 5 and 10 cm. Van den Berg et al. (2012) also reported lower average DOC concentrations in medium and fine-textured Cambisols (mean = 17.4 mg L-1) than in coarser-grained Podzols (mean = 27.4 mg L-1). The above studies show broad ranges of DOC concentrations for the different land use classes, which may be related to site specific factors, such as local climate, land management, soil C:N ratio, soil texture, and sampling depth. The shallower sampling depth in the study by Van den Berg et al. (2012) is likely the reason that they found higher DOC values than the other studies. For the grassland and arable land systems, our model results fall within the ranges reported. However, for the forest systems, our model results generally fall in the lower range or below the reported ranges. This is probably due to the relatively low soil C:N ratio in our simulated forest systems compared to the majority of forest soils for which observations are available.

4. In addition, the authors do a comparison between CENTURY simulations of % SOC and measured values (Table 5), but using several measured values only to 10cm. The implications for the difference between 0 -20cm in model simulations and 0 -10 in measured values is discussed in the text (pg 19641). Measured/modeled SOC comparisons for grassland and forest should be for comparable 0 – 20cm depths, for the reasons stated by the authors. The authors are encouraged to either adjust measured values using a function to extrapolate to deeper depths (e.g. Jobbagy and Jackson 2000), or review literature for additional SOC measurements to 0 -20cm depths.

We have extrapolated the SOC measurements to the 0-20 cm depths using SOC depth distributions as reported by Don et al. (2007) and Braakhekke et al. (2013) for grassland and forest systems, respectively. We have incorporated the outcomes of this conversion in Table 5:

Table 5. Simulated and observed total SOC levels (%) for the three generalized land use types and soil types.

Land use type	Soil type	Simulated SOC[a], g m^{-2}	Simulated SOC[b], %	Observed SOC (median), % Various soil depth ranges	Observed SOC (median), % Converted to 0-20 cm depth	Observed SOC (range[c]), % Various soil depth ranges	Observed SOC (median), % Converted to 0-20 cm depth
Grassland	sandy	3684	1.17	2.30[d]	1.98[g]	1.58–3.43[d]	1.36–2.95[g]
	loamy	4160	1.53	2.90[e]	2.49[g]	1.90–3.10[e]	1.63–2.67[g]
Arable land	sandy	3253	1.04	2.35[d]	2.35[h]	1.65–3.12[d]	1.65–3.12[h]
	loamy	3595	1.32	1.20[e]	1.20[h]	0.95–1.40[e]	0.95–1.40[h]
Forest	sandy	8826	2.81	2.65[d]	2.19[i]	1.96–3.54[d]	1.62–2.92[i]
	loamy	1727	0.63	1.38[f]	1.52[i]	1.03–2.17[f]	1.08–2.63[i]

[a] Total SOC (g m^{-2}) simulated by the Century model for the top 20 cm of soil.
[b] Total SOC (%) resulting from the conversion of the simulated Century model outputs (in g m^{-2}) to gr/100gr, considering a soil bulk density of 1570 kg m^{-3} for the sandy soils, 1360 kg m^{-3} for the loamy soils (as calculated by the online Century model calculator based on soil texture) and a soil depth of 20 cm.
[c] The range refers to the 10th and the 90th percentiles.
[d] Observed values reported by the Province of Noord–Brabant (1996), for the top 10 cm of soil (reference year: 1995).
[e] Observed values reported by RIVM (2014), for the top 10 cm of soil (reference year: 2003 for the grassland system; 2008 for the arable land system).
[f] Observed values by reported by Bodemdata (2014), for various soil sampling depths ranging from 0 to 28 cm (reference year: 1989).
[g] Conversion to 0-20 cm depth based on SOC depth distributions for grassland sites in Germany reported by Don et al. (2007).
[h] No conversion because SOC is assumed to be uniformly distributed across top 20 cm soil layer
[i] Conversion to 0-20 cm depth assuming a logarithmic SOC depth distribution based on data reported by Braakhekke et al. (2013) for deciduous and coniferous forest sites in Germany and the Netherlands.

In the methods section (at the end of section 2.2) we explain how we converted the observed SOC values to average SOC for the top 20 cm. We have modified the paragraph in section 2.3, in which we describe and discuss the results of the comparison accordingly (see also reply to comment 2 by referee#1).

5. The authors are thorough in discussing modeled results in the context of observed directional changes in SOC levels and DOC under different land types and future change scenarios (e.g. pg 19644, lines 20 – 23). However, they do not directly compare the magnitude of model results versus the magnitude of measured and observed change. More explicit comparison would strengthen the analysis.

We agree with the reviewer that a more explicit and detailed reference to the changes reported in other studies would strengthen the discussion of our model results. We have modified the paragraph to which the reviewer refers to and mentioned the changes as found by the other studies and compared them to our results. We briefly discuss the possible explanations for cases when the finding of other studies deviate from ours:

> The future SOC predictions that we present in this paper are in accordance with previous studies that confirmed negative interactions between temperature and SOC levels and positive interactions between precipitation and SOC levels (Jenny, 1941; Jenny, 1980; Parton et al.,

1987; Burke et al., 1989; Schimel et al., 1994; Kirschbaum, 2000; Smith et al., 2005; Gottschalk et al., 2012). Our projected increases of SOC levels in forest systems under the climate change scenarios is in agreement with previous studies, but the magnitude of the projected changes varies. Liski et al. (2002) estimated that the total SOC stocks in European forest soils will increase by about 40% between 1990 and 2040, whereas Smith et al. (2006) projected an increase of only 3.1% to 4.1%. For grasslands, Smith et al. (2005) predicted a slight decrease by 1% or even a slight increase 1.6% in SOC levels for European grasslands between 1990 and 2080, which are much smaller changes than our results indicate. These smaller or even opposite changes in grassland SOC levels can be attributed to a much more enhanced effect of the increase in net primary production and the associated increased organic carbon inputs to grassland soil in the model employed by Smith et al. (2005). In line with our findings, Smith et al. (2005) found that as a result of climate change, SOC contents in European croplands are expected to decrease by 2.8% to 4.4% in 2080 compared to 1990. Post et al. (2008) also projected an overall SOC decline in arable soils in the Elbe River basin by 4.5% between 1990 and 2050 due to climate change. This effect greatly reduced the SOC losses due to direct impacts of climate change on the soil.
A study on the impact of climate change on SOC in agricultural soils in the Mediterranean climate zone (Álvaro-Fuentes et al., 2012a) showed opposite trends compared to our findings. Their study projected SOC gains by 4.5% to 10% in Northeastern Spain by the end of the 21st century due to temperature-induced increase in carbon inputs and precipitation-induced constraints in soil microbial activity. In contrast to our conclusion that the effect of temperature predominates over that of precipitation, Álvaro-Fuentes et al. (2012a) concluded that soil moisture was the main controlling factor of SOC sequestration in Spanish soils.

6. This analysis presents in-depth and realistic scenarios for land management and climate change. The manuscript is well structured, with a clear title, concise abstract, and comprehensive references to related work. However, in the Materials and Methods section the authors are encouraged to more clearly present differences between climate scenarios, land management, and soil texture. The authors could consider moving some information in 2.3.1 and 2.3.2 into table form (or into an expanded Table 2), to show the full factorial of scenarios simulated in the analysis. A table to clarify differences in land management across soil texture classes would be a useful addition, since results by soil texture are conflated with differences in land management.

We have summarised the data for the climate scenarios in Table 2, which was extended, and we removed this information from the text:

Table 2. Changes in temperature and precipitation during winter and summer between the reference year 1990 and 2100, and annual precipitation, mean monthly minimum (T_{min}) and mean monthly maximum (T_{max}) temperatures in 2100 for the different climate change scenarios.

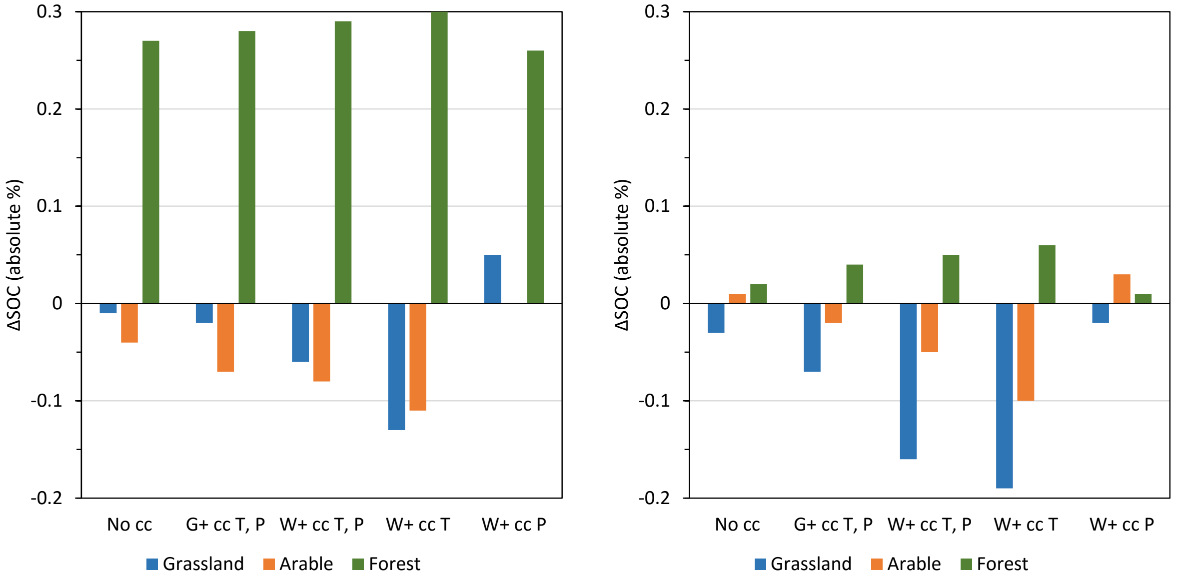
Climate change scenario	ΔTemp		ΔPrec		$Temp_{min}$	$Temp_{max}$	Prec
	winter	summer	winter	summer	(°C)	(°C)	(mm y^{-1})
No cc[a]	0 °C	0	0	0	6.5	14.8	850
W+ cc T,P[b]	+4.6 °C	+5.6 °C	+28%	-38%	8.4	17.4	825
W+ cc T[c]	+4.6 °C	+5.6 °C	0	0	8.4	17.4	850
W+ cc P[d]	0	0	+28%	-38%	6.5	14.8	825
G+ cc T,P[e]	+2.3 °C	+2.8 °C	+14%	-19%	7.0	15.6	839

[a] No-climate-change scenario.
[b] W+ climate change scenario, considering changes in both temperature (T) and precipitation (P).
[c] W+ climate change scenario, considering changes only in temperature (T).
[d] W+ climate change scenario, considering changes only in precipitation (P).
[e] G+ climate change scenario, considering changes in both temperature (T) and precipitation (P).

We agree with the reviewer that this facilitates a direct comparison between the scenarios. In our study, we have not distinguishes different land management scenarios for different soil texture classes. This information can therefore not be presented in a table. We believe that the way we present the land management scenario and its background structured according to the nitrogen gifts via manure and inorganic fertilisers is sufficiently clear to enable reproducing the model calculations.

7. Finally, the authors could consider presenting Figure 4 as a bar chart of net change in SOC% by the end of the simulation period, perhaps grouped by climate scenario rather than by land system/soil texture. This would make change within each scenario easier to compare.

We agree that a figure in which the simulated absolute change in SOC is grouped by climate scenario enables an easier comparison of the changes within each scenario. Therefore, we have changed Fig 4 according to the suggestion by the reviewer:



a. Sandy soil **b. Loamy soil**

Figure 4. Absolute changes in SOC levels (0–20 cm) between 2013 and 2100s in grassland systems, arable land systems and forest systems under the various climate change scenario (T: temperature; P: precipitation; No cc: No-climate-change scenario; G+ cc T, P: G+ climate change scenario considering changes in both T and P; W+ cc T, P: W+ climate change scenario considering changes in both T and P; W+ cc T: W+ climate change scenario considering changes only in T; W+ cc P: W+ climate change scenario considering changes only in P) on a) sandy soil and b) loamy soil.

Technical corrections:

- Pg 19635 line 27- typo, 'op' change to 'of'

'op' has been corrected to 'of'

- Pg 19639 line 21-Statistics were not performed, should not use term 'significant'

The term 'significant' has been omitted

- Pg 19643 paragraph starting line 28- This paragraph seems to be referring to 'all systems with the exception of W+ cc T', which is then discussed in the subsequent paragraph. If so, the exception should be noted.

This is indeed true. We changes the sentence into 'The climate change scenarios for the period 2013–2100 result in a decrease in DOC concentrations and leaching rates for all systems, except for the W+ cc T for the forest systems (Tables 6–8).'