

Biogeosciences Discuss., referee comment RC2
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Comment on bg-2020-489

Anonymous Referee #2

Referee comment on "Additional carbon inputs to reach a 4 per 1000 objective in Europe: feasibility and projected impacts of climate change based on Century simulations of long-term arable experiments" by Elisa Bruni et al., Biogeosciences Discuss., <https://doi.org/10.5194/bg-2020-489-RC2>, 2021

This study used the CENTURY model to simulate the C inputs required for the 4p1000 target to be met, for 14 long-term experiments. Climate data from the past 30 years were used for the simulations. The main findings suggest that the 4p1000 target can be reached with modest increases of exogenous organic matter (EOM) inputs (40-50 %). For two reasons however, this is probably a large underestimate. Firstly, comparison of the SOC changes in the 14 long-term experiments suggest that much larger EOM additions are required to reach the 4p1000 target than suggested by the 'virtual' simulations. Secondly, simulations under warmer conditions show that higher EOM additions will be required in the future than is indicated in the main simulations, in order to compensate for temperature-induced decreases in C stocks.

General comments:

The study is very relevant to current-day topics of interest and it will therefore be of interest to readers of Biogeosciences. The manuscript is generally well written and seems to have been written very transparently (one minor exception, see point 2 below). The introduction is interesting and the breadth of relevant subjects covered in the introduction and discussion is appropriate. The simulations have been carried out thoroughly. My biggest issue with the study is that the results are biased because of the two reasons (given above). Although the authors are honest about the biases in the Results section, the meaning of these biases needs to be communicated more clearly. At the moment, they are communicated adequately in the Discussion but not the Abstract. My suggestion to remedy this is given in point 3 below.

Specific comments:

1. The introduction is interesting, but sometimes strays from the subject of the study.

78-89: This paragraph is too detailed and could be halved in length, especially given it is not the focus of the paper.

90-108: Again, this paragraph is too detailed and could be halved in length, given it is not the focus of the paper.

L109: In contrary, this paragraph is the focus of the paper and needs to be expanded. E.g. the concepts of feasibility and applicability of the 4p1000 need to be introduced; is there doubt that the 4p1000 cannot be reached / maintained ? Why? Are there indications that there is not enough available biomass to reach the 4p1000 aim? State that this study focuses on C inputs only and not on reducing C loss (decreasing mineralisation through cover crops, otherwise reducing erosion).

At the moment there is little justification why this study is necessary.

2. The methods are generally clearly described, with one exception: I have only a basic understanding of the CENTURY model, but as far as I understand from the manual and from Parton et al. (1993), plant C inputs into the soil are based on plant production, as simulated by the model. The authors however calculated plant C inputs based on allometric equations (the approach first described by Bolinder), using user-given yield data as inputs. Is this an alternative version of the CENTURY model? If so, this needs to be explained.

3. This study asks how much C inputs are needed to reach the 4p1000 target i.e. in the future. Because recent climate data were used for the simulations, the result has probably been underestimated, as SOC decomposition rates in a warmer world might be higher than at current. Indeed, this has been demonstrated by similar studies (e.g. Riggers et al 2021, 10.1007/s11104-020-04806-8; Wiesmeier et al. 2016, 10.1038/srep32525). The authors are aware of this and addressed the issue with the so-called 'sensitivity analysis'. This is good, but the outcome of this analysis needs to be related more closely to the main results, especially in the abstract. I therefore suggest that the sentence of L50-51 be moved to the end of the previous paragraph in the abstract, as follows: At the end of the sentence on L 48, add: "This means that the C inputs required to reach the 4p1000 target might actually be much higher. Furthermore, we estimate that annual C inputs will have to

increase even more due to climate warming, that is 54% more and 120% more, for a 1°C and 5°C warming, respectively.”

Furthermore, I recommend the two studies mentioned above be cited in the discussion.

4. L361-363: Isn't this increase in temperature an overestimate? The 1 and 5 degree increases refer to increases between 1996 (roughly half way between 1986 and 2005) and 2090 (roughly half way between 2081 and 2100), i.e. 94 years. The simulations for the study are however run only for 30 years, meaning such temperature increases should not be expected to occur.

5. L496: “farmers may have difficulties in producing or buying high quantities of EOMs” Surely this is not the point: Even if farmers are able to source additional EOMs, these EOMs will then be lacking from other sites (from whence they came), meaning that there is no net removal of CO₂ from the atmosphere -> no C-sequestration. Only if these EOMs would otherwise be mineralised (e.g. burnt) can these be considered sequestration.

6. L632-633: “indicating that lower amounts of carbon inputs might be sufficient to reach the 4p1000 target where SOC stocks are low.” Is this effect (1) merely a calculation effect? i.e. Soils with high SOC stocks need more to reach the 4p1000 target simply because 0.4 % of a higher value is higher (than 0.4 % of a lower value); or (2) is there additionally a ‘true’ effect e.g. the application of 1 t C / ha of EOMs to soils with lower SOC stocks results in a higher SOC gain than 1 t C / ha of EOMs to soils with high SOC stocks?

If the answer is (2), this means that the addition of EOMs to soils with low SOC is much more efficient. This is very important, given that EOMs are a finite resource. In this case, I would also suggest rephrasing the sentence. A suggestion, “indicating that the 4p1000 target can be more efficiently met, i.e. using fewer EOMs, in soils with lower SOC stocks” or “indicating that more C can be stored, and the 4p1000 target more efficiently met, i.e. using fewer EOMs, in soils with lower SOC stocks”

Technical comments:

L30-31: I recommend removing «to promote better agricultural practices». Firstly, it distracts from the focus of the paper and secondly, this is strictly speaking not the aim of the initiative but rather how the aim can be achieved.

L32: The term "straightforward" is ambiguous. Please be more precise.

L36-37: "Initial simulated stocks were computed analytically assuming steady state". I think "initial stocks were simulated assuming steady state" would suffice. Alternatively, consider removing the whole sentence (too much detail for the abstract?).

L40: control plot -> control plots (otherwise it is implied the model was calibrated to the control plot of a single experiment)

L 40-41: "conventional management without additional carbon inputs" Additional to what? Is the term 'no exogenous carbon inputs' meant here? The authors need to be more precise, because in some countries, conventional management does include adding EOMs, e.g. farmyard manure.

L47-48: why "on the *variation* of SOC stocks"? Is not simply "the SOC stocks" meant here? I assume that the SOC stocks are modelled as increasing by 0.25 %? Please specify.

L56: "Strategies of conservation and expansion of existing SOC pools may be necessary but not sufficient to mitigate climate change" The word "are" needs to be inserted before "not sufficient".

L68: "resilience face to changes in climate" -> resilience to changes in the climate.

L71: assessed -> demonstrated (otherwise, depletion of SOC could have been assessed, but have been found to not be the case).

L74: "carbon in the soil" -> "C in the soil" or simply "SOC"

L78: The word 'balance' is inappropriate (they could be unbalanced and SOC stocks would still be present). A suggestion: "SOC stocks are a function of C inputs and C outputs."

L86-89: I understand what the authors mean to say, but fear that this sentence is unclear for readers unacquainted with the literature / concept of C-sequestration. I suggest inserting 'at a given location' between "SOC stocks over time" and "and is not necessarily". It would also be useful to give an example "for example, EOM added to one site is not an example of C-sequestration if it results in loss of EOM at another site".

L90: "for estimating" -> to estimate and "evaluating" -> evaluate

L96: kept on -> maintained

L98: In fact, -> For example,

L104: allow estimating the evolution of SOC stocks and their future trends to assess the potential gain of SOC at global scale -> allow the evolution of SOC stocks and their future trends to be estimated, enabling the potential gain of SOC at a global scale to be assessed, also following changes in agricultural practices.

L127: one control plot -> one control plot in each experiment.

L131: "experiments with a duration of at least 10 years," Surely this is redundant if the experiments all ran for at least 11 years? If this phrase is necessary, please explain what is meant here.

132: except from Foggia -> except for Foggia. It needs to be made clear here that control plots also receive no EOM. I suggest: "C inputs in all sites except for control plots, and all plots in Foggia included..."

L138: remove 'found'

Table 1: Please specify whether 'N' represents the addition of nitrogen or of mineral fertiliser (obviously including nitrogen).

L151: a part -> apart

L154: ratio: should this not be 'rate'?

153-157: I presume the values here all pertain to Table 1. If so, can the authors please recount: the I get only 18 (including the 0.40 score in Arazuni) treatment cases with a

SOC annual variation of $> 0.4\%$. I counted 6 cases where the increase is less than 0.4% and 22 times where there is decrease in SOC stocks.

Figure 1 is not referenced in the text. Please add where appropriate.

L167: Why not give a range for humidity (as for temperature)? This is more useful to know.

L173: Table legend should begin with: "Information about experimental sites" (or something like this).

L197: Please define the term 'SOC(t)' in text

L199: space required between "(t)" and "of"

L235: consists in -> consists of

L243: "By enhancing the computational performance of the simulations". What does this mean? Please be more precise. Or omit.

L244: "this technique enables the analysis of system properties and facilitates studying model behavior." I think this phrase is redundant. Omit? (in which case add "also" between "It and "allowed" in the next sentence.)

L346: please specify what "s is the size of the experiment" means. This is unclear to me.

L369: "fitted quite well the observed SOC stocks" -> fitted the observed SOC stocks well

L370: remove comma in "Fig 4.a, provides"

Figure 4: The colour scheme is nice, but colours need to be more saturated as they are difficult to distinguish from one another if the computer screen is dim.

L383: Could the term 'optimized' be specified here ? e.g. minimum C input additions needed / required to reach the 4p1000 target? Both terms are used elsewhere (e.g. L 422, L451) and make more sense than 'optimized'.

L389: why 'globally'? Is this word necessary here?

L394: per year) -> per year respectively)

L399-400: The absolute increases of the active and passive pool need to be given (so that the 2.7 MgCha-1 can be compared to something).

L410-412: This sentence belongs in the discussion.

L414: How can it be that the TOT C pool requires a lower C input change than all the other pools? I would have expected this pool to be a weighted average of the other pools and thus have an intermediate value.

L452: "increase on average by 54%": please specify what this is compared to. Compared to the C inputs required to meet 4p1000 (CURR) or compared to the control plots of CURR (I presume the former but it's not clear).

L454: "business as usual situation" is this referring to the CURR climate? This is stated in the legend to Fig. 9 but also needs to be stated in the main text.

Figure 9: The y-axis label needs to be changed; at present it implies the average C input change required to reach 4p1000 is a decrease in C inputs (circa 50 %)

C inputs change (%) -> C inputs increase (%)

L466-468: This allowed us: 1) taking into account the average carbon quality of the litter pools in the different crops rotations and 2) correctly estimating the initial values of SOC stocks on the majority of the sites. -> This allowed us to: 1) take into account.... and 2) estimate correctly....

L468: On the other side -> On the other hand

L469: why 'redistribution' ? Is simply 'distribution' meant here?

L468-469: If this is mentioned here, it needs to be discussed in more detail. For example, is there any evidence that this impacted the main outcomes of this study, e.g. the amounts of C inputs required?

L470: Initializing -> initialize

L471: on -> regarding

L472: we decided to optimize -> we optimized

L478-479: It is unclear what is meant by "simulate SOC stocks variation". Is simply "simulate SOC stocks" meant here?

L471: on -> regarding"

L478-483

L502: different whether -> different depending on whether

L507: "The additional carbon is essentially slow" Carbon is not 'slow'. Please rewrite more precisely.

L510-511: we might consider implementing new strategies of additional carbon later on -> new strategies of additional C could be implemented later on.

L512: residues -> residue

L535: I recommend a sentence such as "Thus, Century seems to be over-predicting the effect of adding C inputs in the virtual simulations" after the word "experiments." It would

make the paragraph much easier to read.

L540: in -> for

L542-543: What is meant by this sentence ("The calculation method...")? Please expand.

L543: relatively -> relative

L546: A value of N inputs is given. Why is the term 'proportion' used to describe this amount (in the line above)?

L552: inputs -> input

L552: I recommend: need -> requirement ('need' is correct but because this is also a verb, the sentence is difficult to understand)

L557-571: This section of text is not very focussed and I did not understand what the authors are trying to say. The values cited are important for the discussion of EOMs and agricultural soils, but how does this text relate to the rest of the paragraph?

L573: Is the term 'decreases' meant here instead of 'increases'? Please check.

L577: As we could expect -> As expected (or 'As we expected')

L593-595: This sentence is important, but it needs to be expanded. Most importantly,

inaccuracies / biases in the outcomes of simulations – such as that found in this study – need to be reduced. The authors could incorporate suggestions from L535-538 (e.g. we need to represent the dynamics / timing of C inputs more accurately). Furthermore, the (probable) additional reduction of SOC due to future climate needs to be taken into account.

L594-545: The term 'cut out model uncertainty' is awkward. Multi-model analysis does not strictly speaking omit model uncertainty, but rather acknowledges it and reduces the effect of extreme model outcomes. Please reword.

L601-602: This sentence lacks a context and needs to be written more precisely. I presume the authors mean that SOM will increase decomposition under future (warmer) climates because its decomposition rate is affected – in general increased – with increasing temperatures.

L602-603: remove 'from SOC stocks'

L603: of -> by

L603-604: This sentence needs to be explained. I presume the authors would like to say that there is a diversity of compounds and therefore a diversity of changes that can be expected. As well as the diversity of strength of sensitivity of decomposition rates to future climates, there might also be increases as well as decreases in decomposition rates in the future (e.g. water limitation will reduce some decomposition rates).

L613: inputs -> C inputs

L619: The Davidson and Janssens paper addresses this. If there is space, I recommend to cite this paper again here, and briefly mention how moisture change is important.

L627-628: I would recommend removing this sentence. It is not a generalizable finding but rather is how the authors came to the conclusion that Century over-estimated the effects of the C inputs.

L628-629: might be overestimating -> might have overestimated

L635: The required amount -> Furthermore, the required amount

L636: to substantially increase -> to increase substantially

L636: rising concern on -> raising concern about

L637: SOC stocks -> SOC stock

L638-640: The matter covered in this sentence is not a conclusion reached from this study and it does not fit into the rest of the conclusion. I recommend removing it.

L641: largely depends -> depends largely

L642: only considered -> considered only

L644: is worthwhile to -> should

L645: "to allow for a correct estimation of the uncertainties related to model-specific assumptions" This is too simplistic. Though it would allow the influence of extreme model outcomes to be reduced, if all simulations are biased (e.g. over-estimate the effects of C inputs) then the results of the multi model analysis will also be biased. A more urgent research priority would be to address the cause(es) of the bias(es). See above (response to L593-595). Additionally, EOMs need to be accurately represented in models. The decomposition of biochar for example – the use of which might become more widespread in the future – has very different decomposition dynamics than other EOMs and models need to be adjusted to account for this.

General technical comments:

- The authors use the terms 'site' and 'experiment' interchangeably. I presume these terms relate to the same thing. If so, please use one term only throughout the manuscript (I would suggest 'site').

- Likewise the terms control plots and reference plots (e.g. L473 and in table 1)

- The abbreviation 'SOC' is not used everywhere (e.g. L 418) but should be.

- Likewise, 'C' (carbon).