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Interactive comment on "Impacts of Enhanced Weathering on biomass production for negative emission technologies and soil hydrology" *by* Wagner de Oliveira Garcia et al.

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Dear reviewer, we have carefully reviewed the comments and revised the manuscript. We thank you for constructive remarks and took care to include all of them in the manuscript. We added a detailed reply to each point as addressed below.

Reviewers comment

Our reply

Major comments:

RC2: A number of uncertainties are considered in the paper, but it seems that

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a lot of weight is given to some uncertainties, while other potentially large uncertainties are neglected. For example, only a single CO2/climate scenario is considered and for this particular scenario only results from a single afforestation/bioenergy model is used. What was the reason to choose this particular climate scenario?

The representative greenhouse concentration pathway 4.5 (RCP4.5) was used (Thomson et al., 2011) since it assumes a emission peak around 2040 and considers that forest lands expand from their present day extent (Thomson et al., 2011). Therefore, this CO2 climate scenario seemed to be the most suited for our purposes since forest expansion under the RCP2.6 is lower than that for the RCP4.5 and RCP8.5 scenarios (van Vuuren et al., 2011). The RCP8.5 scenario assumes no climate policy being adopted and consequently the expansion on forest cover does not occur (van Vuuren et al., 2011). There are at least 9 different terrestrial ecosystem models for coupled C-nutrient cycle. We selected the JSBACH since it considers the same level of competition between plants and decomposing microbes for N supply, while other numerical models prioritize immobilization or plant growth (Achat et al., 2016). Based on simulations from Parida (2011), prioritizing the Plant N uptake is unrealistic because soil microbes are more competitive for soil N as compared by plants. Besides that, the selected AR model considers the impacts on biomass productivity due to natural N supply or to N fertilization at a global scale AR deployment (we considered this comment in lines 133 to 148 for AR). Since we want to point out the influence of plant nutrition on biomass growth, using other numerical models would not change our final message (that is: Geogenic nutrient supply can limit biomass growth and consequently reduce the sequestered CO2 potential of large scale AR). This is seen for AR since simulations using the RCP4.5 land pattern that accounted for the RCP8.5 scenario for tree harvest rates and atmospheric CO2 concentrations. The resulting output showed similar areas of forest growth and higher biomass productivity (Sonntag et al., 2016). However, these results did not consider natural N supply and consequently biomass productivity would be N limited, which would decrease the amount of Carbon within Biomass. Similar areas can also be observed in the study from Yousefpour et al. (2019) in Figure 2c for different RCP scenarios. The selected bioenergy model can minimize total costs of production. It also accounts for vegetation composition and distribution for both natural and agricultural ecosystems. Additionally, it considers socio-economic conditions of a system. We selected the RCP4.5 scenario for bioenergy grasses (BG) to keep the MAgPIE simulations corresponding to the JSBACH simulations (we considered this comment in lines 155 to 156 for BG). In the case of BG, to keep high yields or maintain a selected harvest rate, it will be necessary to replenish the exported nutrients by harvest. Therefore, external source of nutrients will be necessary. Accounting for another model rather than MAgPIE would probably change the estimated minimum and maximum harvest rates for Bioenergy grasses, which would impact the necessary amount of rock powder to replenish the exported nutrients due to harvest rates. Thus, we added a hypothetical scenario assuming that the estimated maximum harvest rate by MAgPIE could be increased by one order of magnitude, even though this is unlikely to occur. Adding a scenario accounting for decrease in harvest rates is not necessary, since it is already presented in Fig. 8 from the main text by the filled horizontal lines. However, decreasing the minimum a harvest rate by a factor of two or three also represent a decrease in the minimum amount of rock powder necessary to replenish the exported nutrients by harvest. Since the core messages of our study are: (i) Biomass productivity is limited by geogenic P supply; (ii) EW is an alternative for supplying nutrients besides the potential to keep a net positive CO2 balance; and (iii) the effect of EW on soil hydrology can be neglected in some parts of the world, but EW has the potential to alleviate water stress, at some extent, in areas that drought occurs. Accounting for other models either for AR or bioenergy grasses would not change the general message.

RC2: A discussion on the applicability of the conclusions drawn from the paper to alternative scenarios should be included.

We included the discussion on chapter 4.1 in lines 461 to 467 considering the results from others AR model that assumes RCP8.5 for an RCP4.5 land evolution scenario. And we have also acknowledged your point (that "even using only one model induces uncertainty" the general message of the study would not change) in the last sentence.

We included a discussion for the harvest rates obtained from the MAgPIE simulations. In this discussion we assume a hypothetical one order of magnitude increase in the maximum harvest rate. The discussion is presented on chapter 4.2 in line 488 to 498.

RC2: For the carbon sequestration from afforestation you mention (line 260) that the available estimates of carbon uptake vary between 0.3 and 3.3 GtC/a, while in the paper a value of 2 GtC/a is used.

This is the value for the AR scenario from Kracher (2017), the same model shows a carbon sequestration of 2.4 Gt C a-1 if N supply is unlimited. We have shown that it can fall to 1.3 Gt C a-1 if geogenic P supply scenario one for mean P content within wood and leaves is selected. This number would change for another AR scenario. But the main message is that the estimated C sequestration by biomass on terrestrial carbon cycle models can fall if nutrient supply is accounted for.

RC2: On the other hand, a lot of weight in the uncertainty is given to e.g. the P concentration in basalt (5-95th percentiles). To my understanding it seems that this uncertainty is not so relevant for the present study, as I assume that for the use in EW basalt with relatively high P concentrations could in principle be selected. Would the interquartile range possible provide a more appropriate measure of the uncertainty in this parameter?

For EW, we need to firstly know rock mineralogical composition and petrography. Therefore, it is more interesting a basalt with high pyroxene group minerals content (especially the ones rich in Ca and Mg like Diopside) since these minerals would weather more rapidly (cf. Table 1 at Hartmann et al. (2013)) and less olivine or sulfide minerals content (Olivine can have high content of Nickel and Chromium that are trace elements problematic for agriculture (Edwards et al., 2017); Sulfide minerals can cause acid rock drainage if pyrite (a sulfide mineral) concentration is within 1

RC2: In general in the paper it is difficult to immediately associate the uncertainty ranges to uncertainty sources.

We re-structured the paper. The results are discussed in a separate section. We also renamed the old section "results and discussion" to Discussion and implications, which contain the discussion for the presented results and implications to rock powder deployment.

RC2: For AR it seems that the largest uncertainty is related to the geogenic P-supply, with scenario two showing basically no P limitation. Is there really no observation-based evidence to suggest that one or the other scenario is more realistic? This is a fundamental question for the purpose of the paper, because if P limitation is not an issue the benefit of EW in these areas will be limited to the direct CO2 consumption by weathering.

Basically, the uncertainties for the AR scenario are from biomass P demand and the geogenic P supply, with the later influencing the most our results as it was seen. Unfortunately, given current understanding of bioavailability of soil P and soil P estimates uncertainties are large with respect to how much P is available to support future plant growth (detailed analysis and discussion is found in Sun et al. (2017)) and thus AR and BG. Mineral P is likely limiting biomass production in European forests today (Jonard et al., 2015), tropical forest (Turner et al., 2018), boreal forests (Shinjini et al., 2018), as well as agricultural areas (e.g., Ringeval et al., 2019 in discussion;Kvakić et al., 2018). This situation is likely to deteriorate in the future. Therefore, considering that the inorganic and organic labile P pools will be completely available for tree nutrition is unlikely to occur. Thus, Geogenic supply Scenario 2 is a very optimistic assumption that might not correspond to reality based on the already observed P limitation on different ecosystems (Elser et al., 2007). However, we cannot rule out that gradual shifts in soil organic P fractions occur, which make comparable amounts of P as in scenario

2 available over time, We therefore opted to show both scenarios as these are a major source of uncertainty with respect to P effects on future plant growth (as has been demonstrated by Sun et al. (2017)).

RC2: In the main text there are many references to supplementary materials. References to supplementary material should be limited as much as possible for a better readability of the paper, considering also that papers in Biogeosciences are not subject to strict length limitations. Since the main paper contains only relatively few figures, I would suggest to move some of the figures from the supplementary to the main paper. For example Figs S1,S2,S3 could be merged into one figure and added to the paper. It would help to get an idea of the numbers that could then be more easily compared with e.g. the P gap in Fig. 2. I would also strongly suggest to add Fig. S8 to the main paper.

We appreciate your suggestions and have considered them. Now the Figs. S1 to S3 is the Fig. 3 in the mains text. The Fig. S8 now is the Fig. 4 in the main text (which also include the estimated P gaps for the AR scenario).

RC2: The results for the N-unlimited scenario, which are not discussed in the main text, could be presented in a separate section in the supplementary material. It is very confusing to find figures from N-unlimited experiments mixed inbetween N-limited figures.

Now in the Chapter B from the supplementary material we have the results for the AR N-limited for the 5th and 95th quartile of wood P content in the subchapter 'i'. The AR N-unlimited results are presented within the subchapter 'ii'.

Minor comments:

RC2: Figures should be numbered progressively according to where they are referenced in the text (i.e. Fig. 1 should be referenced before Fig. 2). This is valid also for figures in the supplementary.

We did the suggestion. You can find it in the supplementary file S1.docx line 47 to 53.

RC2: Line 21-22: you need to mention what scenario you are considering here, otherwise the numbers make no sense since they will be strongly dependent on future CO2/climate evolution.

Now we explicitly correlate the amount sequestered for each geogenic P supply scenario and AR P demand (high, corresponding to 95th quartile of wood chemistry and low corresponding to 5th quartile of wood chemistry). Line 20 to line 25.

RC2: Line 23: 'K' not defined here

Now it is defined (line 26).

RC2: Line 22: it would be helpful if the same unit would be used, either GtC or GtCO2. Otherwise it is difficult to compare the numbers.

Now they are in the same unit (GtC) line 25.

RC2: Line 95: '...we discuss only the N-limited AR scenario...'

We did the change, you can see it in line 102.

RC2: Line 119: please check this sentence

The sentence was deleted.

RC2: Line 147: are these numbers global averages for the areas with bioenergy plantations?

No, they are global minimum and maximum. They are necessary since for bio-energy crops the amount of exported nutrients by harvest need to be replenished to keep with the specific harvest rate. The sentence was reformulated, you can see it in line 164.

RC2: Line 186: nearest neighbour interpolation does not seem to be a very good interpolation choice for very high resolution input data (e.g. geogenic P release rates). A single 1 km^2 value will not be very representative for a 2x2 cell

No, according to Christman and Rogan (2012) the nearest-neighbor scaling method can keep with the overall proportions of the original fine resolution map. This is because the interpolant exhibits the smallest variation of the interpolant function while meeting the measured data. Since we are interested in P concentrations (supplied by weathering, atmospheric deposition, or different soil pools) the degree of discontinuity is very high (i.e., they are spatially and temporally heterogeneous) and using a more robust interpolation algorithm (i.e., Cubic-Spline) could result in new minima and maxima values in the original maps, which would be a wrong result. If the Best Linear Unbiased Estimator (i.e., Kriging) algorithm is selected, it would be necessary to know the proper semivariogram function or assume one based on tests to check its appropriateness or on the uncertainty estimation. Therefore, to preserve the limits of different geogenic P release rates represented by the fine resolution map from Hartmann et al. (2014) and due to its simplicity compared to the other interpolation algorithms, we selected the nearest-neighbor interpolation method. You can see these justifications in line 202 to line 204.

RC2: Line 425: where does this number come from?

We rephrased the sentence. Now you can find it in line 592.

References

Christman, Z. J., and Rogan, J.: Error Propagation in Raster Data Integration, Photogrammetric Engineering Remote Sensing, 78, 617-624, 2012. Garcia, d. O. W., Amann, T., and Hartmann, J.: Increasing biomass demand enlarges negative forest nutrient budget areas in wood export regions, Scientific Reports, 8, 5280, 10.1038/s41598-018-22728-5, 2018. Hartmann, J., West, A. J., Renforth, P., Köhler, P., De La Rocha, C. L., Wolf-Gladrow, D. A., Durr, H. H., and Scheffran, J.: Enhanced chemical weathering as a geoengineering strategy to reduce atmospheric carbon dioxide, supply nutrients, and mitigate ocean acidification, Reviews of Geophysics, 51, 113-149, 10.1002/rog.20004, 2013. Jonard, M., Furst, A., Verstraeten, A., Thimonier, A., Timmermann, V., Potocic, N., Waldner, P., Benham, S., Hansen, K., Merila, P., Ponette, Q., de la Cruz, A. C., Roskams, P., Nicolas, M., Croise, L., Ingerslev, M., Matteucci, G., Decinti, B., Bascietto, M., and Rautio, P.: Tree mineral nutrition is deteriorating in Europe, Glob Chang Biol, 21, 418-430, 10.1111/gcb.12657, 2015. Kracher, D.: Nitrogen-Related Constraints of Carbon Uptake by Large-Scale Forest Expansion: Simulation Study for Climate Change and Management Scenarios, Earth's Future, 5, 1102-1118, 10.1002/2017EF000622, 2017. Sonntag, S., Pongratz, J., Reick, C. H., and Schmidt, H.: Reforestation in a high-CO2 worldâĂŤHigher mitigation potential than expected, lower adaptation potential than hoped for, Geophysical Research Letters, 43, 6546-6553, 10.1002/2016gl068824, 2016. Thomson, A. M., Calvin, K. V., Smith, S. J., Kyle, G. P., Volke, A., Patel, P., Delgado-Arias, S., Bond-Lamberty, B., Wise, M. A., Clarke, L. E., and Edmonds, J. A.: RCP4.5: a pathway for stabilization of radiative forcing by 2100, Climatic Change, 109, 77, 10.1007/s10584-011-0151-4, 2011. van Vuuren, D. P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G. C., Kram, T., Krey, V., Lamarque, J.-F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S. J., and Rose, S. K.: The representative concentration pathways: an overview, Climatic Change, 109, 5, 10.1007/s10584-011-0148-z, 2011. Achat, D. L., Augusto, L., Gallet-Budynek, A., and Loustau, D.: Future challenges in coupled C–N–P cycle models for terrestrial ecosystems under global change: a review, Biogeochemistry, 131, 173-202, 10.1007/s10533-016-0274-9, 2016. Christman, Z. J., and Rogan, J.: Error Propagation in Raster Data Integration, Photogrammetric Engineering Remote Sensing, 78, 617-624, 2012. Earle, S.: Physical geology, 2018. Edwards, D. P., Lim, F., James, R. H., Pearce, C. R., Scholes, J., Freckleton, R. P., and Beerling, D. J.: Climate change mitigation: potential benefits and pitfalls of enhanced rock weathering in tropical agriculture, Biology letters, 13, 20160715, 2017. Elser, J. J., Bracken, M. E. S., Cleland, E. E., Gruner, D. S., Harpole, W. S., Hillebrand, H., Ngai, J. T., Seabloom, E. W., Shurin, J. B., and Smith, J. E.: Global analysis of nitrogen and phosphorus limitation of primary producers in freshwater, marine and terrestrial ecosystems, Ecology Letters, 10, 1135-1142, doi:10.1111/j.1461-0248.2007.01113.x, 2007. Hartmann, J., Moos-

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dorf, N., Lauerwald, R., Hinderer, M., and West, A. J.: Global chemical weathering and associated P-release - The role of lithology, temperature and soil properties, Chemical Geology, 363, 145-163, 10.1016/j.chemgeo.2013.10.025, 2014. Irvine, T., and Baragar, W.: A guide to the chemical classification of the common volcanic rocks, Canadian journal of earth sciences, 8, 523-548, 1971. John, W.: An introduction to igneous and metamorphic petrology, 552.1 W 784552.1 W 784552.1 W 784552.1 W 784, 2001. Kvakić, M., Pellerin, S., Ciais, P., Achat, D. L., Augusto, L., Denoroy, P., Gerber, J. S., Goll, D., Mollier, A., Mueller, N. D., Wang, X., and Ringeval, B.: Quantifying the Limitation to World Cereal Production Due To Soil Phosphorus Status, Global Biogeochemical Cycles, 32, 143-157, 10.1002/2017gb005754, 2018. Parida, B.: The influence of plant nitrogen availability on the global carbon cycle and N2O emissions, University of Hamburg Hamburg, 2011. Porder, S., and Ramachandran, S.: The phosphorus concentration of common rocksâĂŤa potential driver of ecosystem P status, Plant and soil, 367, 41-55, 2013. Ringeval, B., Kvakić, M., Augusto, L., Ciais, P., Goll, D., Mueller, N. D., Müller, C., Nesme, T., Vuichard, N., Wang, X., and Pellerin, S.: Insights on nitrogen and phosphorus co-limitation in global croplands from theoretical and modelling fertilization experiments, Biogeosciences Discuss., 2019, 1-35, 10.5194/bg-2019-298, 2019. Shinjini, G., C., F. M., A., V. M., Mariann, G. J., D., Y. R., and J., F. T.: Phosphorus limitation of aboveground production in northern hardwood forests, Ecology, 99, 438-449, doi:10.1002/ecy.2100, 2018. Sun, Y., Peng, S., Goll, D. S., Ciais, P., Guenet, B., Guimberteau, M., Hinsinger, P., Janssens, I. A., Peñuelas, J., Piao, S., Poulter, B., Violette, A., Yang, X., Yin, Y., and Zeng, H.: Diagnosing phosphorus limitations in natural terrestrial ecosystems in carbon cycle models, Earth's Future, 10.1002/2016ef000472, 2017. Turner, B. L., Brenes-Arguedas, T., and Condit, R.: Pervasive phosphorus limitation of tree species but not communities in tropical forests, Nature, 555, 367-370, 10.1038/nature25789, 2018. Yousefpour, R., Nabel, J. E., and Pongratz, J.: Simulating growth-based harvest adaptive to future climate change, Biogeosciences, 16, 241-254, 2019.

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