Interactive comment on **"Biological weathering and its consequences at different spatial levels – from nanoscale to global scale"** ***by*** **Roger D. Finlay et al.**

Anonymous Referee #2

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In General:

The authors of the paper propose a review of current (last 10 years) of advancement made in the understanding of biological weathering, specifically focusing on the boreal forest, in response to an interdisciplinary project called "Quantifying weathering rates for sustainable forestry." This topic fits well the scope of BG and it is needed to help us move forward in this area of research.

Good that the topic fits and that an article like this is needed.

The manuscript cites more than 200 references that span a wide range of topics from physical, chemical and biological approaches, and scales from nano-scale empirical studies to global scale modeling, and emphasizing an evolutionary viewpoint on biological weathering. However, I was disappointed seeing that about 1/3rd of the references are prior to 2009 and have been widely cited and reviewed in the past, thus these do not give "anything new" especially in some sections of the manuscript (see details below) and it also contradicts with the authors aim of summarizing the last 10 years of advancement.

We understand this reasoning but inclusion of some older references is necessary to provide perspective and to explain the development of different types of experiments. We will try to reduce the proportion of older references by cutting some of the older ones.

The manuscript is a well-written review/summary of more than the last 10 years of bio- logical weathering research with a heavy emphasis on mycorrhizae mediated weathering (which is the ecosystem in the boreal forest). However, there is no synthesis of the reviewed literature, there is no agreement stated on what is the current understanding, or state of this biological weathering in the boreal forest, and how it applies to sustain- able forestry or simply how to move forward. The manuscript is a review, but it lacks a synthesis.

We agree that the aims of the article are not clearly stated and that the final take home message is not made clearly enough. We will try to provide the desired synthesis more clearly by re-structuring of the manuscript.

Regardless of great writing, it was not an easy read, because I could not find/follow the purpose of this manuscript, it presents a lot of data on both side of the arguments that contradict each other, which is fine, however, there are no directions, there is a lot of rambling on without focus – what is the underlying message? What do the authors want to achieve with this review? Key questions and knowledge gaps section is underdeveloped and it seems like it was an afterthought and stuck to the end.

We are pleased that the reviewer considers the writing was good but agree the take-home message was not stated clearly enough. In the revision we will address this problem and try to provide more focus. We agree that the last section is too superficial and under-developed. It was included too close to the initial deadline and will be expanded to provide clearer guidance about key knowledge gaps and necessary approaches to resolving conflicting opinions in future experiments.

In addition, I think that the title is misleading, as the review is really about weathering in the boreal forest. Most cited work was done by researchers related to the boreal or other forests (field), in the laboratory using mostly conifers and mycorrhizal fungi, and there are couple of "side topics" that seems to be out of place in this bigger scheme (for example, the hydraulic lift study for drought-prone ecosystems).

We agree that the main emphasis is on boreal forests, although the section on evolutionary aspects includes a discussion of processes that took place before the evolution of terrestrial plants. Other components of different ecosystems are also mentioned in this section including 1. proteoid roots of in highly weathered soils, 2. calcicole plants in calcareous soils, 3. non-mycorrhizal fungi such as different Aspergillus species and 4. different bacterial species. If the handling editor considers it appropriate we can add a secondary part to the title such as "- with particular emphasis on boreal forests."

Some specifics:
Abstract and 1. Introduction – no specific comments.
2. Microscale/nanoscale observations of physical alteration of minerals: This section is heavily based on older findings and mention some new studies, but it is unclear what advances were made in the last 10 years – new techniques? New understanding of processes? Or just supporting previous findings? Or all above? It needs a refocus, and it can be shortened by about half and still convey the same message.

We agree, in part, with this assessment and will try to emphasize more recent studies involving the application of new techniques, and to explain more clearly what advances have been made – where appropriate. This section is only about 880 words (6.8 % of the article) and not excessively long but we will attempt to reduce the length.

3. Biofilms and small-scale microbial interactions with consequences at higher spatial scale: how are these differently categorized than the next section, which is about microbial and plant secretions? EPS, biofilm, oxalic acids etc. are secretions, are not? What are the consequences at higher spatial scale? Do we know? Or is it a challenge to scale things up? Again, what is the new advancement in the last 10 years? The section needs some clarifications and/or refocus.

The interactions in this section take place at a smaller spatial scale than those discussed in the subsequent section where plants or microorganisms are cultured in micro- or mesocosms. Admittedly there is some overlap between these sections since these small-scale processes also take place in single plant-scale interactions studied in microcosms, but we will re-write to improve clarity and focus.

4. Microbial and plant secretions – evidence from microcosms and mesocosms: long section – rambling on without focus, lots of info and data about various roles, functions, and processes of mycorrhizal fungi, but no other components of the ecosystem, and the hydraulic lift section seems irrelevant in the boreal forest. Bringing in drought may be something we want to think about as climate shifts, but it most likely causing larger problems in drought-prone parts of the world.

*We disagree about other components not being mentioned in this section. Other components of (different) ecosystems **ARE** mentioned in this section including **1.** proteoid roots of plants growing in highly weathered soils, **2.** calcicole plants growing in calcareous soils, **3.** non-mycorrhizal fungi such as different Aspergillus species and **4.** different bacterial species. We will try to add some more comments about other non-mycorrhizal fungi and lichens. We will*

also try to reduce the rambling and improve focus. We can remove the reference to hydraulic lift if necessary.

5. Systemic consequences of microorganism-mineral interactions in an ecological and evolutionary context: this is really important and interesting, however, it is too long, have some repetition – I am not sure why the 5.1. section is separated (elevated) from the rest of 5. – Weathering, nutrient acquisition, carbon allocation, and sequestration are the key elements of the evolutionary viewpoint – perhaps, this section could be rearranged and shortened to synthesize our current understanding of the evolution of plants and associated fungi in the context of carbon and nutrient cycling. Bob Berner did the pioneering work in this field with his carbon models, but it got a lot of attention in the last 10 years, so a focused synthesis would help us to identify future directions.

We agree that this section can be made more concise and can be re-arranged. We want to retain the evolutionary focus to underline the fundamental nature of the interactions between microorganisms and minerals but we can provide more of a focused synthesis about future directions of research and outstanding questions.

6. Methods using stable isotopes: The section is interesting, provide laboratory evidence of the usefulness of these techniques in addition to field studies, however, the last paragraph states that the "there is no clear evidence that processes observed at the laboratory-scale play a significant role in "soil-scale" mineral dissolution rates." This indicates that laboratory studies are useless, why do we bother then? Is there anything we learned from the laboratory studies? Also, the last paragraph is a repetition of statements on page 12 lines 13-15.

We have agreed to remove this statement from the last paragraph. We will also re-write this section to avoid any repetition.

7. Modelling of weathering in forest soils: this whole section is unfocused. It starts with the PROFILE and ForSAFE models, then it talks about information needs and possible improvements (in 7.1.) and then it returns to talk about a bunch of other models in too much detail without getting to a point. This section should synthesize what are the main outcomes of the different modeling approaches (probably in half of the length), and identify what is missing (information) and how to tackle the shortcomings.

We agree with these comments and will re-write this section according to the recommendations. It will be re-organized and shorted substantially.

8. Conclusions: I was expecting to find the key questions, knowledge gaps and future directions (or call for specific areas of research) in this section.

We agree that this section could be usefully combined with Section 9 (which is much too short). We will expand the key conclusions and have a clear presentation of the major knowledge gaps as well as clear recommendations about how these can be solved. – To identify the key questions and what future approaches/measurements are needed to answer them.

Figures: Not all necessary – Figure 1, 2, 4, 6, 7 do not add new information to the summary (synthesis) or not necessary to understand the text. Figure 9 and 10 are a good representation of specific examples for laboratory approaches. Figure 3, 5, 8, and 11 are great illustrations of processes and their interactions from small to large scales.

We agree with this assessment of the necessity (or not) of the figures. The non-essential ones were provided to make the article more self-contained but can be omitted to make the article shorter. Figures 4 and 6 at least show what mycorrhizas look like and show a pictorial representation of what they do (in terms of C allocation). Potentially the article may be read by many people who have limited knowledge of mycorrhizal structures and these would improve understanding.

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