Response to Reviewer 2 Comments

This review paper provides an overview of the application of biochar as an amendment for the remediation of heavy metals contaminated soil. This topic is very hot in recent years and within the scope of the journal. The review content is comprehensive, which is helpful for other researchers working in the same areas. Overall, the writing is commendable and the presentation of the content is very clear. However, more details should be provided in some parts of the paper. The reviewer has some comments and suggestions to help the authors to further improve the quality of the review manuscript. If the authors are willing to revise, the manuscript can be considered for publication in Molecules. The general and details comments are summarised as follows.

**Question 1:**

When discussing the interactions between biochar and soil heavy metals, the mobility of heavy metals in unsaturated contaminated soil is an important factor that affects the biochar-HM interactions. Soil hydraulic properties affect the mobility of heavy metals. Hence, the influence of biochar on soil hydraulic properties (water retention and hydraulic conductivity) should be also reviewed. Even though authors conclude that biochar can improve soil water holding capacity in the Abstract, but there is no content about this in the main text. Regarding the biochar effects on soil hydraulic properties, the authors can refer to the following articles “Effects of biochar on water retention and matric suction of vegetated soil”, “Two-year evaluation of hydraulic properties of biochar-amended vegetated soil for application in landfill cover system”, “Influence of biochar addition on gas permeability in unsaturated soil” and others.

**Answer 1:**

It is a very perfect ideal to consider the effect of biochar on heavy metals from the perspective of soil hydraulic properties. In the Section 4.2, the influence of biochar on soil hydraulic properties (water retention and hydraulic conductivity) is added. Some
thinkings can be drawn from these three articles. Biochar can reduce soil bulk density and improve soil water retention and hydraulic conductivity, which is related to the high porosity of biochar. The increase of soil water retention and hydraulic conductivity improved the activities of soil enzymes and microorganisms to a certain extent, which enhanced the remediation effect of soil microorganisms on heavy metals pollution, thus reducing the mobility and toxicity of heavy metals in the soil. Generally speaking, the researchers applied biochar in a certain proportion and maintained the soil moisture content at 70% of the maximum field water holding capacity for soil incubation experiments. Therefore, the increase of soil water holding capacity and hydraulic conductivity can indirectly reflect the heavy metals remediation efficiency and plant growth tendency.

**Question 2:**

For the future perspectives, the authors should extend this section by including the possible methodologies to achieve those proposed future topics. The current last paragraph is too brief. In addition, the measures to mitigate the negative effects of biochar on soil environment and heavy metal remediation should also be discussed in detail.

**Answer 2:**

Thank you very much for your valuable comments. The contents of the manuscript have been revised according to this evaluation. This is my negligence in writing the paper, thank you again.

**Question 3:**

In each subsection of Section 4 “Remediation of soil HMs contamination by biochar”, more details should be provided regarding the time efficiency of each heavy metal remediation by using different biochar types.

**Answer 3:**

The manuscript has been revised in accordance with the review comments, thank you very much for your reminder. Information on biochar types, soil types, biochar
application rates, heavy metals treatment effects, and time efficiency are summarized in Table 2 of the manuscript. In short, Table 2 is a brief summary of the Section 4 “Remediation of soil HMs contamination by biochar” of this article, and the Section 4 is the detailed analysis of Table 2 (analysis of the mechanisms between biochar and heavy metals).

**Question 4:**

In section “3.4. pH values”, only alkaline biochar is reviewed. Actually, some biochars can be acidic. Please also review and discuss the acidic biochar and its influence on soil pH as well as soil heavy metal remediation.

**Answer 4:**

According to the review comments, the summary of acidic biochar was added to the manuscript. Thank you very much for your supplement to the first draft, which makes the content of this article more substantial. The content of acidic biochar is summarized as follows:

However, in some studies, the biochar produced by hydrothermal carbonization are typically acidic [1]. For example, the pH value of Miscanthus-derived hydrochar prepared by Gronwald et al. [2] at 200°C is 3.8, and Cui et al. [3] found that the pH value of Hydrocotyle verticillata-, Myriophyllum spicatum- and Canna indica-derived hydrochar (200°C) are 5.07, 4.97 and 6.48. Liu et al. [4] adjusted the pH value of the initial solution (pH = 2, 3, 5, 7, 9, 11, 12) of the hydrothermal carbonization process, so that the pH value of the prepared sewage sludge-derived hydrochar was still weak acid or neutral (corresponding pH = 5.05, 6.11, 7.24, 6.60, 6.62, 6.74, 6.94). The presence of carboxyl functional groups on the surface of hydrochar as a result of formation of acetic and formic acids during the hydrothermal carbonization process could be the reason for the low pH value [5].

**Reference:**

2. Gronwald, M., Helfrich, M., Don, A., Fuß, R., Well, R., Flessa, H. Application of


Except that the pH value of biochar produced by hydrothermal carbonization is acidic, the pH value of biochar prepared by other methods is mostly alkaline. Moreover, the pH value of biochar increases with the increase of preparation temperature. Therefore, generally speaking, high temperature biochar is alkaline. The focus of this review is to summarize the application of pyrolytic biochar (pH is mainly alkaline), that is to say, the application of pyrolytic biochar in heavy metals contaminated soil (pH is mainly acidic). On the one hand, the alkaline pH value of pyrolytic biochar can be used to immobilize heavy metals. On the other hand, it can improve the acidic environment of soil, stimulate soil respiration and enhance the immobilization of heavy metals. However, the acidic biochar (hydrochar) is more suitable for alkaline soil in North China, and its purpose is to neutralize the acidity of soil lime, improve soil environment and increase crop yield. In addition, the soil heavy metal pollution in South China is generally more serious than that in North China, especially in cadmium, lead and arsenic. Most of the soils in South China are acidic, especially paddy soils, so it is more effective to apply alkaline biochar to southern soils.

Question 5:
What are the typical ranges of biochar particle size produced at different pyrolysis temperatures? What are the effects of biochar particle size on soil properties and biochar-heavy metal interactions?

**Answer 5:**

Large biomass particle size tends to produce biochar with high yield and large particle size (Leng et al. 2018). Generally speaking, researchers commonly screen biomass materials with different particle sizes, then pyrolysis them at different temperatures, and finally grind and screen the biochar to the desired range. For example, Liu et al. (2018) milled peanut shell biomass to obtain raw materials with different particle sizes (<0.075, 0.075–0.150, 0.150–0.300, 0.300–2.00 mm). After 500°C pyrolysis, ground the produced biochar to the size in the range from 0.149 to 0.850 mm. Results shows a maximum increase in bio-oil yield and a decrease in biochar yield with decreasing biomass particle size. The variation of biochar particle size with pyrolysis temperature is rarely reported in the literature. Therefore, the research on the effects of biochar particle size on soil properties and the interaction between biochar and heavy metals is not very prominent. Most researchers have milled and screened biochar to below 2 mm for the remediation of heavy metals contamination in soils, and carried out soil incubation experiments and plant pot experiments, such as Yin et al. (2017), Qiao et al. (2018), Gonzaga et al. (2018), Zheng et al. (2015) and Zhou et al. (2019). But there are also grinding to finer particle sizes, such as Kim et al. (2018) sieved to below 0.15 mm, Gao et al. (2019) sieved to below 0.45 mm. The detailed biochar-heavy metal interactions and treatment effects are listed in Table 2 (in manuscript). Theoretically, biochar with smaller particle size has relatively larger specific surface area and stronger binding capacity with heavy metals compared with the larger particle size biochar. Usually, biochar itself is a kind of adsorption material with larger specific surface area, so it is not very necessary to study the effect of particle size.

**Reference**


Question 6:

L155: There are two “changed”. One should be deleted.

Answer 6:

Thanks for your patience in reviewing this manuscript, I will revise it soon.