Journal of Rice Science

Mini Review **ISSN: 2690-5183 |Volume 1**

Long-Term Effects of Biochar on Mitigating Methane Emissions from Paddy Soil

Qina Y[1*], Nana Q[1], Xin L[1] and Wu W[1]

[1]Department of Environmental Science and Technology, College of Environment and Resource Science, Zhejiang University, Hangzhou 310029, P. R. China

***Corresponding author:**
Yong Qin,
Department of Environmental Science and Technology,
College of Environment and Resource Science,
Zhejiang University,
Hangzhou 310029, P. R. China,
E-mail: weixiang@zju.edu.cn

Received: 02 Jun2023
Accepted: 18 Jul 2020
Published: 14 Aug 2020

Citation:

Qina Y, Long-Term Effects of Biochar on Mitigating Methane Emissions from Paddy Soil. Journal of Rice Science. 2020; 1(4): 1-4.

1. Abstract

Biochar has been reported to mitigate short-term methane emissions from paddy soil. At present, methane mitigation by biochar has primarily focused on the abundance and variations of methanogens and methanotrophs, and changes in their activity during methane production and consumption. However, long-term effects of biochar on methane mitigation from paddy soil remain controversial. In this review, we highlighted two existing opinions on the long-term methane mitigation effect upon biochar application. Combining the already explored mechanism of fresh biochar on methane mitigation from paddy soil and a novel discovery, that chemical reactivity of biochar can also stimulate anaerobic oxidation of methane, we analyzed the possible influences of biochar on methane production and consumption during its aging.

Global warming is a major problem for humankind. Methane (CH_4) is an important greenhouse gas, contributing up to 20% to global warming [1, 2, 3, 4]. Wetlands, including paddy fields, are an important source of CH_4 emissions [5, 6, 7]. Flooded paddy soil contributed to 25% of the CH_4 emissions from agricultural soil in 2017 [8]. Thus, reducing CH_4 emissions from paddy fields is a major concern for alleviating global warming [9].

Biochar has been reported as a promising material for mitigating CH_4 emissions from paddy soil [10, 11, 12]. Biochar is a black-colored product produced as a result of biomass pyrolysis under limited oxygen [13]. It has been explored as an avenue for carbon sequestration, crop yield increase, and mitigation of CH_4 emissions [14-19]. Rice husk and maize straw have been reported to significantly reduce cumulative CH_4 emissions as per meta-analysis [11]. Ji (2020) [20] reported significantly reduced CH_4 emissions using biochar in an incubation experiment conducted for 77 days. Annual biochar application at a low rate (2.8 t ha-1) has also been reported to reduce CH_4 emissions by 41% from paddy, on an average, over a span of five years [21]. Ecological benefits of biochar application have been widely recognized internationally. The ‘2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventory’ newly added biochar to the calculation method of the annual change in the organic carbon storage of mineral soil [22]. This suggests an international recognition of biochar for its ecological benefits.

The mechanism by which biochar facilitates the mitigation of CH_4 emissions from paddy soil was examined in terms of the effect of biochar attributes on soil physicochemical and microbial structure. Generally, most of the explored mechanisms focus on the influence of biochar on the activity changes in methanogens and methanotrophs during CH_4 mitigation [23, 10, 12, 24, 19]. It is generally believed that biochar application in soil mainly promotes CH_4 oxidation activity [23, 21, 24]. Biochar is porous and alkaline [25, 26] the former attribute provides a satisfactory habitat for methanotrophs to increase CH_4-capturing ability and decrease Al^{3+} toxicity [20, 27]. The alkaline attribute of biochar usually increases soil pH to the optimum range for methanogens and methanotrophs [28]. Methanotrophs are more sensitive to soil pH, and therefore, CH_4 oxidation activity substantially increases compared to methanogenic activity [29]. Furthermore, the use of large particle size biochar in soil increased soil aeration, and enhanced CH_4 oxidation activity. These findings revealed that biochar promoted aerobic CH_4 oxidation activity.

Recently, positive effects of biochar on anaerobic CH_4 oxidation activity induced by the electronic accepting capacities of biochar have also been observed. Biochar can act as an electron acceptor as well as a donator, facilitating CH_4 production and oxidation [30-32]. O-containing functional groups are the main entities responsible for the Electron Accepting Capacities (EAC) and Electron Donating Capacities (EDC) of biochar. Carbonyl and quinone determine the EAC properties of biochar. Zhang et al. (2019b) [32] reported that biochar stimulates the anaerobic oxidation CH_4 due to the presence of C=O. Phenolic groups, quinone/hydroquinone moieties, and condensed aromatic (sub-) structures of biochar that allow electrons to be transferred across the conjugated p-electron systems are the main sources of EDC. Biochar with a high EDC value is beneficial for promoting methanogenic activity [33, 34]. Hence, EDC and EAC are also important factors in assessing the effect of biochar on CH_4 mitigation in paddy soil.

However, most studies that have demonstrated satisfactory results on CH_4 mitigation from paddies, to date, have mainly focused on the CH_4 mitigating effect in pot experiments and short-term experiments. In contrast, observations from field studies and long-term effects, especially after years of biochar aging, are lacking; in other words, the efficacy of biochar in mitigating CH_4 emissions after years of aging remains to be explored.

Opinions on the effect of aged biochar in reducing CH_4 emissions from rice paddies differ. One opinion is that biochar, after four or six years of aging, still effectively mitigates CH_4 emissions, as suggested by pot/incubation experiments [28, 12]. Some other studies demonstrated that fresh biochar significantly decreased cumulative CH_4 emissions from paddy fields but showed no significant difference from the control group after one year of aging [21, 35]. The main reason for this is that fresh biochar increased CH_4 oxidation potential in the first year, while this effect decreased with its aging [21]. Spokas (2013) [36] also reported that biochar aging decreased the ability to promote methanotroph activity. To maximize the long-term CH_4 mitigation effect of biochar from paddies, the mechanism underlying the mitigation effect of aged biochar needs to be further explored.

Theoretically, the exploration of the mechanism should first focus on changes in biochar attributes. Agricultural activities, such as plowing and tillage, usually occur during the fallow period [17, 37]. After years of rice growth, farming, and fallow cycles, biochar particles become smaller resulting in an increase in their exposed surface area [17]. This facilitates the formation of smaller-sized soil aggregates compared to those produced when fresh biochar is applied [38]. These smaller soil aggregates hamper effective soil aeration. Hence, when large soil aggregates are fractured into smaller ones, the soil electric potential (Eh) would decreases, which may promote methanogenic activity. In addition, small soil aggregates present a much weaker barrier between microorganisms and organic matter [39], indirectly increasing substrate availability for methanogens. During rice tillering and jointing growth stage, the ash content of biochar dissolves and leaches, leading to the gradual disappearance of the liming effect [40, 41]. Smaller biochar particles accelerate the biochar oxidation rate by exposing more biochar surfaces to oxidation by root secretions and oxides. Aged biochar is characterized by a higher number of O-containing functional groups such as carboxyl C, carbonyl C, and phenolic OH [13]. It has been reported that after four months of soil incubation, biochar quinone content decreased [42]. As quinone mainly contributes to EAC, and phenolic OH is the main EDC source, changes in O-containing functional group changes inevitably affect methanogenic and CH_4 oxidation processes [30, 32]. Therefore, to reveal the mechanism of the effect of aged biochar on CH_4 emissions, the key step is to explore the metabolic differences between methanogens and methanotrophs based on changes in the physicochemical and electrochemical properties of the biochar.

Hence, further research should focus on specifying biochar-specific properties that greatly impact methanogenic and CH_4 oxidation processes. Studies have reported the effect of biochar particle size on CH_4 emission [43, 44], and the changes in biochar particle size during biochar aging are evident. However, few studies have focused on changes in CH_4 emissions from paddy soil based on biochar EAC/EDC and soil aggregate distribution; these may be proved to be other important factors that affect CH4 emissions in paddy soil. In addition, although pot and short-term field experiments are usually feasible operationally and economically results may not adequately reflect the scenario is under actual field conditions. Hence, long-term field positioning experiments, based on soil-plant-atmosphere ecosystems, must be conducted to obtain the most reliable results and CH_4 mitigation mechanisms in paddy fields upon biochar application.

2. Acknowledgements

This research was supported by the National Key Technology Research and Development Program of the Ministry of Science and Technology of China [grant number 2015BAC02B01]and National Natural Science Foundation of China [grant number 41571241]. We thank the editors and reviewers for their constructive comments.

References:

1. Ma J, Chen W, Niu X, Fan Y. The relationship between phosphine, methane, and ozone over paddy field in Guangzhou, China. Global Ecology and Conservation. 2019; 17: e00581.
2. Nguyen BT, Trinh NN, Bach QV. Methane emissions and associated microbial activities from paddy salt-affected soil as influenced by biochar and cow manure addition. Applied Soil Ecology. 2020; 152: 103531.
3. Ye S, Zeng G, Wu H, Liang J, Zhang C, Dai J, et al. The effects of activated biochar addition on remediation efficiency of co-composting with contaminated wetland soil. Resources, Conservation and Recycling. 2019; 140: 278-85.
4. Zhang XB, Xu J. Optimal policies for climate change: A joint consideration of CO2 and methane. Applied Energy. 2018; 211: 1021-9.
5. Bridgham SD, Hinsby CQ, Keller JK, Zhung Q. Methane emissions from wetlands: biogeochemical, microbial, and modeling perspectives from local to global scales. Global Change Biology. 2013; 19; 1325-46.
6. Ma K, Qiongfen Q, Yahai L. Microbial mechanism for rice variety control on methane emission from rice field soil. Global Change Biology. 2010; 16: 3085-95.
7. Xiao Y, Yang S, Xu J, Ding J, Sun X, Jiang Z. Effect of Biochar Amendment on Methane Emissions from Paddy Field under Water-Saving Irrigation. Sustainability. 2018; 10: 1371.
8. FAOSTAT. 2020. Food and agriculture organization of the united nations (FAO), Vol. 2020.
9. Bertora C, Peyron M, Pelissetti S, Grignani C, Sacco D. 2018. Assessment of methane and nitrous oxide fluxes from paddy field by means of static closed chambers maintaining plants within headspace. Journal of visualized Experiments. 2018; 139: 56754.
10. Han X, Sun X, Wang C, Wu M, Dong D, Zhong T, et al. Mitigating methane emission from paddy soil with rice-straw biochar amendment under projected climate change. Scientific Report. 2016; 6: 24731.
11. Awad YM, Wang J, Igalavithana AD, Tsang DCW, Kim KH, Lee SS, et al2018. Chapter One - Biochar Effects on Rice Paddy: Meta-analysis. in: Advances in Agronomy, (Ed.) D.L. Sparks, Vol. 148, Academic Press, 2018; pp: 1-32.
12. Wu Z, Song Y, Shen H, Jiang X, Li B, Xiong Z. Biochar can mitigate methane emissions by improving methanotrophs for prolonged period in fertilized paddy soils. Environmental Pollution. 2019; 253: 1038-46.
13. Mia S, Dijkstra FA, Singh B. Long-Term Aging of Biochar. 2017; 141: 1-51.
14. Dong D, Wang C, Van Zwieten L, Wang H, Jiang P, Zhou M, et al. An effective biochar-based slow-release fertilizer for reducing nitrogen loss in paddy fields. Journal of Soils and Sediments,. 2020; 20: 3027-40.
15. El-Naggar A, El-Naggar AH, Shaheen SM, Sarkar B, Chang SX, Tsang DCW, et al. Biochar composition-dependent impacts on soil nutrient release, carbon mineralization, and potential environmental risk: A review. Journal of Environmental Management. 2019; 241: 458-67.
16. Sarfraz R, Yang W, Wang S, Zhou B, Xing S. Short term effects of biochar with different particle sizes on phosphorous availability and microbial communities. Chemosphere. 2020; 256: 126862.
17. Sha ZL, Qianqian L, Tiantian LV, Misselbrook T, Liu X. Response of ammonia volatilization to biochar addition: A meta-analysis. Science of The Total Environment. 2019; 655; 1387-96.
18. Wang DF, Mark LF, Scow MK. Impacts and interactions of biochar and biosolids on agricultural soil microbial communities during dry and wet-dry cycles. Applied Soil Ecology. 2020; 152: 103570.
19. Yang S, Ya'nan X, Sun X, Ding J, Jiang Z, Xu J. Biochar improved rice yield and mitigated CH4 and N2O emissions from paddy field under controlled irrigation in the Taihu Lake Region of China. Atmospheric Environment. 2019; 200: 69-77.
20. Ji M, Zhou L, Zhang S, Luo G, Sang W. Effects of biochar on methane emission from paddy soil: Focusing on DOM and microbial communities. Science of The Total Environment. 2020; 743: 140725.
21. Nan Q, Wang C, Wang H, Yi Q, Wu W. Mitigating methane emission via annual biochar amendment pyrolyzed with rice straw from the same paddy field. The Science of the total environment. 2020a; 746: 141351.
22. IPCC. IPCC 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. 2019.
23. Dong D, Yang M, Wang C, Wang H, Li Y, Luo J, et al. Responses of methane emissions and rice yield to applications of biochar and straw in a paddy field. Journal of Soils and Sediments. 2013; 13; 1450-60.
24. Yang M, Liu Y, Sun X, Dong D, Wu W. Biochar improves methane oxidation activity in rice paddy soil. Transactions of the Chinese Society of Agricultural Engineering. 2013; 29: 145-51.
25. Hardie M, Clothier B, Bound S, Oliver G, Close D. Does biochar influence soil physical properties and soil water availability? Plant and Soil. 2014; 376: 347-61.
26. Liu J, Qiu H, Wang C, Shen J, Zhang W, Cai J, et al. Effects of biochar amendment on greenhouse gas emission in two paddy soils with different textures. Paddy and Water Environment. 2020.
27. Qian L, Baoliang C. Interactions of Aluminum with Biochars and Oxidized Biochars: Implications for the Biochar Aging Process. Journal of Agricultural and Food Chemistry. 2014; 62: 373-80.
28. Wang C, Jianlin S, Liu J, Qin H, yuan Q, Fan F, et al. Microbial mechanisms in the reduction of CH4 emission from double rice cropping system amended by biochar: A four-year study. Soil Biology and Biochemistry. 2019; 135: 251-63.
29. Jeffery S, Verheijen FGA, Kammann C, Abalos D. Biochar effects on methane emissions from soils: A meta-analysis. Soil Biology and Biochemistry. 2016; 101: 251-8.
30. Klupfel L, Keiluweit M, Kleber M, Sander M. 2014. Redox proper-

ties of plant biomass-derived black carbon (biochar). Environment Science&Technolgy. 2014; 48: 5601-11.

31. Zhang X, Xia J, Pu J, Cai C, Tyson GW, Yuan Z, et al. Biochar-Mediated Anaerobic Oxidation of Methane. Environ Sci Technol. 2019a; 53: 6660-8.
32. Zhang Y, Xu X, Zhang P, Ling Z, Qiu H, Cao X. Pyrolysis-temperature depended quinone and carbonyl groups as the electron accepting sites in barley grass derived biochar. Chemosphere. 2019b: 232: 273-80.
33. Cruz Viggi C, Simonetti S, Palma E, Pagliaccia P, Braguglia C, Fazi S, et al. Enhancing methane production from food waste fermentate using biochar: the added value of electrochemical testing in pre-selecting the most effective type of biochar. Biotechnology Biofuels. 2017; 10; 303.
34. Shao L, Li S, Cai J, He P, Lu F. 2019. Ability of biochar to facilitate anaerobic digestion is restricted to stressed surroundings. Journal of Cleaner Production. 2019; 238: 117959.
35. Nan Q, Wang C, Yi Q, Zhang L, Ping F, Thies JE, et al. Biochar amendment pyrolysed with rice straw increases rice production and mitigates methane emission over successive three years. Waste management (New York, N.Y.). 2020b; 118: 1-8.
36. Spokas KA. Impact of biochar field aging on laboratory greenhouse gas production potentials. Global Change Biology Bioenergy. 2013; 5: 165-76.
37. Yi Q, Liang B, Nan Q, Wang H, Zhang W, Wu W. Temporal physicochemical changes and transformation of biochar in a rice paddy: Insights from a 9-year field experiment. Science of the Total Environment. 2020; 721: 137670.
38. He L, Zhao J, Yang S, Zhou H, Wang S, Zhao X, et al. Successive biochar amendment improves soil productivity and aggregate microstructure of a red soil in a five-year wheat-millet rotation pot trial. Geoderma. 2020; 376: 114570.
39. Keefer TC, Dan GZ, Roger EG. 2013. Evaluation of Aggregate Particles as a Physical Barrier to Prevent Subterranean Termite Incursion Into Structures. Southwestern Entomologist. 2013; 38: 447-64.
40. Chang R, Sohi SP, Jing F, Liu Y, Chen J. A comparative study on biochar properties and Cd adsorption behavior under effects of ageing processes of leaching, acidification and oxidation. Environment Pollution. 2019; 254: 113123.
41. Lou L, Luo L, Cheng G, Wei Y, Mei R, Xun B, et al. The sorption of pentachlorophenol by aged sediment supplemented with black carbon produced from rice straw and fly ash. Bioresource Technology. 2012; 112: 61-6.
42. Mukome FND, Kilcoyne ALD, Parikh SJ. Alteration of Biochar Carbon Chemistry during Soil Incubations: SR-FTIR and NEXAFS Investigation. Soil Science Society of America Journal. 2014; 78: 1632-40.
43. He X, Yin H, Sun X, Han L, Huang G. Effect of different particle-size biochar on methane emissions during pig manure/wheat straw aerobic composting: Insights into pore characterization and microbial mechanisms. Bioresource Technology. 2018; 268: 633-7.
44. Sriphirom P, Amnat C, Yagi K, Boonapatcharoen N, Tripetchkul S, Towprayoon S. 2020. Effects of Biochar Particle Size on Methane Emissions from Rice Cultivation. Journal Of Renewable Materials. 2020; 8; 1199-214.