Proceedings of ICEGEE 2026 Symposuim: AI-Based Medicine and Biological Data Analysis
DOI: 10.54254/2753-8818/2026.AU33185

# The Impact of Straw Biochar Returned to the Fields on Methane Reduction in Rice Fields

**Ruiqi Yang[1*], Yanning Zhang[2]**

[1]*College of Resources and Environment, Hubei University, Wuhan, China*
[2]*College of Agricultural, Hunan Agricultural University, Changsha, China*
**Corresponding Author. Email: 195899.5347@stu.hunau.edu.cn*

***Abstract.*** The carbon cycle is a crucial method for achieving carbon neutrality. Researches show that methane emissions in rice fields account for 30% of total methane emissions from global agricultural sources. Methane emissions are one of the main factors contributing to global climate change and the greenhouse effect. Straw incorporation is an effective path to use agricultural waste resources. To reduce methane emissions in rice fields and utilize agricultural waste resources more efficiently, this research examines the impact of straw biochar returned to the fields on methane reduction. The research systematically reviews the fundamental characteristics and preparation methods of straw biochar, discusses the ways in which straw biochar application to the soil alters the soil condition, its impact on soil structure, and the mechanism of reducing methane emissions. This article aims to provide scientific evidence for the carbon cycle regulation method of promoting methane emission reduction through the application of straw biochar in the field, in order to facilitate the achievement of carbon neutrality.

***Keywords:*** Straw, Biochar, Methane, Soil structure, Carbon neutrality

## 1. Introduction

With the rapid development of rice production in China, a series of new problems and challenges have gradually emerged. Among them, the impact of straw biochar returning to paddy fields on methane emission reduction is particularly prominent, becoming a key factor restricting the further development of this field. At present, studies on the mitigation effect of biochar on methane in paddy soil mainly focus on the abundance and changes of methanogens and methanotrophs, as well as the changes in their activities during methane production and consumption [1]. It has been confirmed that biochar can reduce short-term methane (CH4) emissions from paddy soil, but its long-term impact remains controversial.

In recent years, scholars at home and abroad have conducted extensive research on straw biochar returning to paddy fields and methane emission reduction in rice paddies, accumulating a large amount of survey data, statistical information and literature achievements. Wang Chaodong's team found that the alternate wetting and drying irrigation combined with straw returning technology (AWD+SC/SS) can significantly enhance the accumulation and translocation of photosynthetic products in rice, improve root growth in the rhizosphere, and achieve the dual goals of increasing

DOI: 10.54254/2753-8818/2026.AU33185

rice yield and reducing greenhouse gas emissions from paddy fields [2]. However, despite numerous research findings, the problem of methane emissions from paddy fields has not been fundamentally solved, and the underlying hierarchical causes and mechanisms remain to be further explored.

Therefore, this study aims to conduct an in-depth analysis of four aspects: the properties and preparation methods of straw biochar, the ways and effects of biochar amendment on soil properties, the mechanisms of biochar in reducing methane emissions, and the growth performance of rice crops under methane mitigation. On this basis, it further discusses the causes and impacts of biochar on methane emission reduction in paddy fields, and proposes feasible solutions, so as to provide theoretical support and practical guidance for the sustainable development of this field.

## 2. Straw biochar's basic properties and preparation methods

### 2.1. Basic properties

Straw biochar is rich in carbon and capable of stable carbon sequestration. The total carbon content of some products can reach or exceed 30%, making it an important material for agricultural carbon sink enhancement and emission reduction. In addition, straw biochar contains nutrients required by plants such as nitrogen, phosphorus and potassium, and can be used as a raw material for fertilizers. According to the research by Yuan Shuai, Zhao Lixin and other co-authors, which summarized the pH characteristics of biochars derived from different biomass materials, the pH of straw biochar mostly ranges from 8 to 11, while that of livestock manure biochar is higher and that of woody biochar is relatively stable. The pH of straw biochar is related to the contents of inorganic minerals (e.g., carbonates and phosphates) and ash formed during pyrolysis and carbonization, enabling it to ameliorate acidic soils [3].

Straw biochar features a well-developed pore structure with high porosity and a large specific surface area, generally ranging from 1.5 to 500m2·g-1. Within a certain temperature range, the specific surface area increases with rising pyrolysis temperature but may decrease beyond the critical temperature. Straw biochar has a low bulk density and loose texture, which help alleviate soil compaction [3].

The well-developed pore structure and large specific surface area of straw biochar enable it to adsorb heavy metals, organic pollutants and soil nutrients, thus reducing nutrient loss. Owing to its highly aromatic carbon skeleton, low H/C atomic ratio, high carbonization degree, hydrophobic surface structure and stable surface functional groups, straw biochar is chemically stable and can persist in soils for a long time to exert continuous effects [4].

### 2.2. Preparation methods

Preparation of straw biochar includes these key factors such as pyrolysis temperatur, heating rate and heating methods. In addition, due to differences of these factors in preparation process, the methods for preparing biochar have been divided into pyrolysis method, hydrothermal method and microwave method, among them, the pyrolysis method is the most traditional and widely used method [5,6].The pyrolysis method is devided rapid pyrolysis and slow pyrolysis based on reaction temperature and length of reaction time, its main method is constantly heating to decompose the organic principle in the straw, after that reorganize the free radicals, preparing biochar by producing amorphous carbon in the end [5]. Besides, among the other preparation methods, hydrothermal method involves using water as the medium and place it in a specific container ,its compound method for synthesizing materials under high temperature and high pressure conditions; microwave

DOI: 10.54254/2753-8818/2026.AU33185

method is using electromagnetic wave leading to the polar molecules within the straw biomass experience intense collisions, under the effect of high-frequency collisions, the huge friction heat provides a short-term heating effect for the biomass, thereby acheiving the production of biochar [5].

## 3. Ways and influences of straw biochar amendment on changing soil status

Straw biochar systematically improves soil conditions through physical structure optimization, chemical property regulation, and carbon cycle control. As a soil conditioner, biochar application promotes soil carbon emission reduction, optimizes soil structure, exerts considerable effects on soil physical and chemical properties, improves the soil environment, and thus promotes crop growth.

### 3.1. Physical structure optimization

The porous structure of biochar provides physical support for soil particles. Functional groups such as hydroxyl (-OH) and methyl (CH3) on its surface bind with soil minerals via hydrogen bonds and covalent bonds. For example,-OH groups in biochar combine with water molecules between montmorillonite layers or -OH on the surface of silicon-oxygen tetrahedra through hydrogen bonding, leading to an increase in the interlayer spacing of clay minerals (from 1.2 nm to 1.5 nm). Meanwhile, biochar particles adhere to mineral surfaces, significantly enhancing the physical stability of biochar and increasing the content of large macroaggregates [6,7].

The honeycomb pore structure of biochar reduces soil bulk density and increases total porosity. Moreover, the interconnected pores between biochar particles facilitate gas exchange and prevent soil compaction [7].

### 3.2. Chemical property regulation

Carbonates and oxygen-containing functional groups in biochar can neutralize H+ in acidic soils and raise soil pH [7]. Meanwhile, through hydroxylation precipitation and functional group complexation, biochar transforms highly toxic Al3+ into low-toxic forms, alleviating the inhibition of aluminum toxicity on crop roots. Biochar also directly increases soil organic carbon (SOC) content and synergistically improves the stability of the carbon pool through fractions such as light fraction organic carbon (LFOC) and mineral-associated organic carbon (MAOC) [8].Its carbon stability index (SCI) is much higher than that of traditional straw returning. The pore structure and functional groups of biochar can adsorb nutrients such as nitrogen, phosphorus, and potassium, reducing leaching loss, while slowly releasing nutrients for crop uptake.

### 3.3. Carbon cycle

Biochar significantly reduces CH4 emissions from paddy fields by adsorbing methanogenic substrates and optimizing the pore oxygen environment. At the same time, its surface functional groups promote the activity of N2O reductase thereby mitigating nitrous oxide emissions [9]. Under different water conditions, the inhibitory effect of biochar on CH4 emissions is more stable. Compared with straw returning, biochar amendment results in a lower loss rate of soil organic carbon and can maintain low carbon loss even under alternate wetting and drying conditions, showing more significant effects on carbon sequestration and emission reduction.

DOI: 10.54254/2753-8818/2026.AU33185

### 3.4. Biochar's influence on soil physical properties

Soil's ventilation and water content are important factors that affect soil structure and the growth of crops, it is also an important factor influencing soil fertility, named soil aggregates. Soil aggregates are more stable, soil structure and erosion resistance will be more stable. Apply biochar to the soil, using quality of the high specific surface area, rich oxygen-containing functional groups, porous structure and high carbon content of biochar, changing the physical properties of the soil, such as porosity and bulk density, further enhancing the soil's water retention capacity and air permeability, and improving the soil temperature [7].

Soil generally contains large pores, which will influence the growth of the crop's root system as well as the activities of various microorganisms in soil, only by increasing porosity can improve the soil environment. Biochar has porous structure and low density, this characteristic can improve the problem of large pores in the soil, at the same time, according to the experimental research shows, application rate of different biochars(0.1% to 30%),pyrolysis temperature (400 to 600 ℃ ),host material and agrotype, all of these will have an impact on the soil porosity [7]. Therefore, needing to apply appropriate biochar to interact with the mineral particles in the soil, thereby dividing the large pores in the soil into smaller pores [7], soil density are reduced. As the soil porosity increases, the ventilation and water retention properties of the soil have also been significantly improved, meanwhile, it also can increase the nutrient content in the soil and promote the growth of crops.

According to Singh, Horiák, Zhao and Liu's research, biochar was prepared respectively from wood, herbaceous plants, wood waste and corn stalks [7]. After conducting field trials, it was discovered that the volume of soil did not show any significant change. Field experiments have more unstable conditions compared to laboratory experiments, which is easily affected in uncontrolled environmental factors, but it has no significant impact on the interaction between biochar and soil. Besides, biochar prepared from the same crop under different temperatures is applied to the soil, there is no significant change in soil density either. Therefore, the density of biochar produced under different conditions does not show significant differences from that of the soil [7].

### 3.5. Biochar's influence on soil chemical properties

Biochar has a positive effect on soil cation exchange capacity (CEC),which prepare temperature is an important factor influencing the degree of enhancement of soil CEC. Biochar was prepared and applied at a temperature range of 300 to 400 ℃ ,promotes soil CEC value to be relatively high; biochar was prepared and applied at a temperature range of 400 to 500℃,soil CEC will decrease as the preparation temperature of the biochar rises; when applied with the biochar prepared at 500℃,soil CEC will reduce 50% [6].In addition ,biochar is applied to the soil where it reacts for a long period of time within the soil, thereby the oxygen-containing functional groups formed due to soil surface oxidized also have an important role in enhancing the CEC of the soil, the oxygen-containing functional groups higher, the soil CEC will be stronger [6].

Acidic soil also has a significant impact on the growth of crops, biochar's surface contains negatively charged carboxyl, hydroxyl and phenolic groups that can neutralize hydrogen, then it can neutralize the hydrogen in the soil solution, reducing hydrogen's concentration, thereby changing acidic soil, increasing the pH value of acidic soil [6].

DOI: 10.54254/2753-8818/2026.AU33185

## 4. The mechanism which biochar reduces methane emissions

In the global carbon emission volume, the proportion of carbon emissions from agricultural production is relatively high. Among them, methane is the main factor contributing to carbon emissions in agricultural production, in order to reduse methane emissions and use agricultural wastes reasonably, and because biochar can reduce methane emissions, converting straw back into biochar to reduce methane emissions. The generation, oxidation and migration of methane are all important factors for methane emissions. The mechanism by which biochar reduces methane emissions is shown in Figure 1 [10].

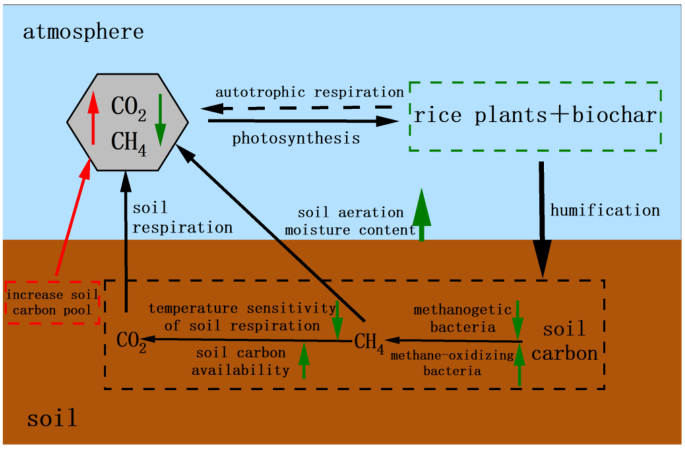


Figure 1. The mechanism which biochar reduces methane emissions [10]

### 4.1. Physical aspect

In terms of physical effects, biochar has a large specific surface area and a loose with porous structure, using its strong adsorption capacity, it can enhance the soil's ability to absorb methane, thus reducing mechane's emissions [10].

In terms of physical properties, biochar can change soil aeration conditions, moisture content and soil humidity to reduce formation and emission of methane, which can inhibit the formation of colonies that promote methane production while enhancing the formation of oxidizing bacteria [10].

### 4.2. Chemical aspect

In terms of chemical properties, applying biochar to the soil can effectively inhibit methane formation process from the very beginning [10]. Because biochar can improve soil pH value, reduced colony activity of promoting mechane generation, and the colony of decomposing methane will increase in activity. Biochar can also promote the oxidation of methane, pH value's increase can enhance the activity of oxidizing bacterial colonies, and it can also promote the development of crop roots while enhancing the activity of root oxidase. Under the action of dual oxidation, methane can be accelerated for decomposition and oxidation, thereby reducing mechane emissions, promoting carbon neutrality [10].

DOI: 10.54254/2753-8818/2026.AU33185

### 4.3. The treatment of methane by biochar as a cover material

The mechanism by which biochar affects methane treatment of the cover layer is essentially to transform the emission source into an absorption source. In all the treatments of the coverings, methane will be released in the first year, biochar will be applied to the soil the following year. Biochar can transform methane emission sources into absorption sources, reducing methane emissions. According to the research conducted by KAYES I et al, the covering inducing methane emissions mainly has a positive impact on the total organic carbon and soil moisture content of the soil, the outer protective tissue covering of the crop not only provides organic matter but also has strong water retention properties in the meantime [11]. In environments with high water content, the oxygen content in the soil will significantly decrease, meanwhile, covering has the ability to dissolve organic compounds. Under this environment, the microorganisms and colonies that promote methane emissions will multiply in large numbers, resulting in a large amount of methane emissions. In order to avoid the excessive generation of methane in the covering material and in high-humidity environments, biochar should be added to reduce soil organic matter. Reducing soil organic matter can help to improve soil porosity, accelerating the oxidation of methane, decreasing its emissions [11].

## 5. Crop growth in paddy fields following methane mitigation

At present, the main approaches to reducing methane emissions while achieving stable or even increased crop yields include breeding low-methane rice varieties and applying microalgal biofertilizer combined with precise fertilization.

### 5.1. Breeding of low-methane rice varieties

Fumarate and ethanol are the two major rice root exudates that play key roles in regulating methane emissions. Fumarate released in the rhizosphere is metabolized by microorganisms, supporting the growth of methanogenic archaea that produce methane as the terminal carbon product. In contrast, ethanol mitigates methane emissions by inhibiting the activity and growth of methanogens and reducing fumarate synthesis in rice roots [12]. In addition, deep nitrogen placement (DN) is emerging as a promising strategy, which is more effective in reducing methane emissions. By applying a higher nitrogen rate, DN mainly reduces organic matter decomposition and inhibits the abundance of the soil mcrA gene, and can reduce global paddy $CH_4$ emissions by 14.6% [13]. Low-methane rice varieties allocate more photosynthates to grains, increasing yields by approximately 20% while enhancing stress resistance.

### 5.2. Microalgal biofertilizer and precise fertilization

Compared with conventional fertilization, root application of microalgae at a medium dose significantly increased crop yield by 15.7% to 29.6%, while a high dose significantly increased soluble sugar content and reduced sugar accumulation. Although microalgae did not increase greenhouse gas emissions except for high-dose root application, leading to higher nitrous oxide, root application actually significantly increased methane uptake by 1.5 to 2.3 times [14]. In addition, microalgae application increased soil organic carbon content, and significantly elevated soil dissolved organic carbon, microbial biomass carbon, as well as soil ammonium nitrogen and dissolved organic nitrogen at the medium dose. Overall, the results demonstrate that living

DOI: 10.54254/2753-8818/2026.AU33185

microalgae can be used as a green biofertilizer to increase crop yield without increasing greenhouse gas emission intensity [14].

## 6. Conclusion

The research systematically expounded on how biochar affects soil structure and methane emission mechanisms from three aspects: physics, chemistry and biology, which has been completely established "biochar→soil improvement→methane emission reduction" action chain. Straw biochar has a well-developed pore structure and a greater specific surface area, which can effectively adsorb methane in the fields of physics and chemistry. At the same time, it can also increase the pH value and promote the oxidation and decomposition of methane, improving soil fertility, thereby reducing methane emissions, promoting the growth of crops, carbon emissions have been reduced. Besides,the combination of biochar returned to the fields and selection of low-methane rice varieties, which make the dual emission reduction advantages of "materials + varieties", achieving a win-win situation for both the environment and production.

The research has enriched the theory of carbon and nitrogen cycling in the paddy field ecosystem, deepened the understanding of the regulatory mechanism of microbial communities mediated by biochar, and it has provided new scientific evidence for the reduction of greenhouse gas emissions from agriculture. The straw biochar returned to the fields not only reduces the pollution and waste caused by agricultural waste to the environment, but also achieves methane emission reduction through the carbon cycle, thereby promoting carbon neutrality. This approach achieves a synergistic effect of methane emission reduction and agricultural productivity enhancement.

Through the research, it cannot only focus on the straw biochar returned to the fields, but it can also conduct research on the application of biochar for other crops as well, exploring the effects of applying biochar from different crops to the soil. With the advancement of technology and in order to obtain more precise data and more accurate and convenient operations, remote sensing monitoring, Internet of Things sensors and AI prediction models can be introduced in the research to achieve dynamic perception and precise regulation of greenhouse gas emissions after the application of biochar. Research has confirmed that biochar has a significant effect on methane reduction in the short term. However, based solely on short-term experimental data, there are still uncertainties. The functional stability of biochar after aging, the differences in long-term effects under different regions and climatic conditions; the impact on the long-term succession of soil microbial communities are all still unclear, and there is a lack of long-term, location-based experiments independently conducted for verification. In the future, long-term positioning experiments need to be strengthened. Combined with remote sensing monitoring and AI models, a comprehensive assessment of the long-term ecological effects of biochar should be conducted.

## Authors contribution

All the authors contributed equally and their names were listed in alphabetical order

## References

[1] Nan, Q., Xin, L. Q., Qin, Y., Waqas, M., & Wu, W. X. (2021). Exploring long-term effects of biochar on mitigating methane emissions from paddy soil: a review. Biochar, 3(2), 125-134.

[2] Wang, C. R., Zhang, N., Ru, Y., Yan, Y., Meng, Q. H., Wen, Y., Zhang, Y., Xiao, Z. L., & Zhang, H. (2025). Effects of alternate wetting and drying irrigation and straw returning modes on rice yield and greenhouse gas emissions. Chinese Journal of Rice Science, 1-15.

DOI: 10.54254/2753-8818/2026.AU33185

[3] Varkolu, M., Gundekari, S., Palla, V. C. S., Kumar, P., Bhattacharjee, S., & Vinodkumar, T. (2025). Recent Advances in Biochar Production, Characterization, and Environmental Applications. Catalysts, 15(3).
[4] Wang, J., Shi, L., Zhai, L. L., Zhang, H. W., Wang, S. X., Zou, J. W., et al. (2021). Analysis of the long-term effectiveness of biochar immobilization remediation on heavy metal contaminated soil and the potential environmental factors weakening the remediation effect: A review. Ecotoxicology and Environmental Safety, 207.
[5] He, M. F., Wang, Z. H., Zhang, Y., et al. (2025). Research Progress on the Removal of Heavy Metals from Water by Straw Biochar. Shandong Chemical Industry, 54(4), 135-138.
[6] Xu, L., Zhao, F., Peng, J., Ji, M., & Li, B. L. (2025). A Comprehensive Review of the Application and Potential of Straw Biochar in the Remediation of Heavy Metal-Contaminated Soil. Toxics, 13(1), 69.
[7] Zhu, Z. T., Zhang, Y., Tao, W. M., Zhang, X. L., Xu, Z. D., & Xu, C. C. (2025). The Biological Effects of Biochar on Soil's Physical and Chemical Characteristics: A Review. Sustainability, 17(5).
[8] Chen, M. W., Liu, D. Q., Shao, X. J., Li, S. P., Jin, X., Qi, J. C., et al. (2024). Effect of Biochar Types and Rates on SOC and Its Active Fractions in Tropical Farmlands of China. Agronomy-Basel, 14(4).
[9] He, Y. W., He, Y. D., Al-Dhabi, N. A., Gao, P., Huang, H. L., Yan, B. H., et al. (2024). Effects of exogenous thermophilic bacteria and ripening agent on greenhouse gas emissions, enzyme activity and microbial community during straw composting. Bioresource Technology, 407.
[10] Sun, Y., Wang, X., Yang, C., Xin, X., Zheng, J., Zong, T., & Dou, C. (2024). Effects of Biochar on Gaseous Carbon and Nitrogen Emissions in Paddy Fields: A Review. Agronomy, 14(7), 1461.
[11] Kayes, I., Halim, M. A., & Thomas, S. C. (2025). Biochar mitigates methane emissions from organic mulching in urban soils: Evidence from a long-term mesocosm experiment. Journal of Environmental Management, 376.
[12] Jin, Y. K., Liu, T., Hu, J., Sun, K., Xue, L. H., Bettembourg, M., et al. (2025). Reducing methane emissions by developing low-fumarate high-ethanol eco-friendly rice. Molecular Plant, 18(2), 333-349.
[13] Zhu, X. C., Chen, N. N., Li, W. W., Tang, J. Q., Huang, Y. F., Qian, H. Y., et al. (2025). Quantifying the global methane mitigation potential of deep nitrogen placement in rice paddies. Resources Conservation and Recycling, 219.
[14] Ma, F., Li, Y. C., Han, X., Li, K., Zhao, M. Y., Guo, L. P., et al. (2024). Microalgae-based biofertilizer improves fruit yield and controls greenhouse gas emissions in a hawthorn orchard. PLoS One, 19(8).