

# Differential Analysis of Biochar Effects on Soil Physicochemical Properties

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**Abstract.** For a long time, because of China's large population and small per capita resource occupancy, the use of natural resources is unreasonable. Soil degradation problem due to the long-term irrational utilization of land resources is becoming more and more serious, which seriously damaging the ecological environment and hindering China's modernization process. Facing the problem of soil remediation, biochar technology has become a research hotspot because of its advantages of green environmental protection, low cost, high efficiency, and wide application. And black soil in northeast China and southern region of red soil as important soil types of agroforestry in China, over the years have experienced serious soil degradation crisis. In this paper, black soil and red soil are selected as research objects to explore the impact of biochar on the physical and chemical properties of the two soils. This paper intends to use the methods of investigation and analysis, and comparison in many aspects. Through the study, it was found that the application of biochar had the same trend of influence on the organic carbon content and C/N ratio of the two soils, but the index of black soil increased more significantly. The change trend of soil bulk density and pH was also consistent with the application of biochar, and the difference was not significant. The effects of biochar applied to the two soils on greenhouse gas emissions were quite different. The soil health of black soil and red soil is of great significance in China's agricultural production and life. This paper expects to bring reference value to the improvement of the overall soil function and the promotion of ecological restoration process of China's biochar modification work for different soil types in the north and south, by comparing the impact of biochar on the physical and chemical properties of the two soils. A better soil improvement program can be obtained after comparative analysis, so as to provide suggestions on sustainable development and comprehensively promote ecological construction.

**Keywords:** Biochar, Degradation, Red soil, Black soil, Physicochemical Properties.

## 1. Introduction

Over the decades, due to the sustainable development of our country industrialization and the constant improvement of the demand for food, in many parts of the soil is experiencing serious soil degradation problems. Statistically, about 460 million hectares of soil are degraded due to soil erosion, salt evolution, marsh, soil fertility attenuation and acidification, accounting for 40% of the country's land area and 1/4 of the world's total soil degradation area [1]. At present, soil degradation in China mainly includes soil fertility degradation, soil acidification, soil secondary salinization and alkalization. From the perspective of soil fertility, the organic matter content of cultivated land in China is generally low, and most paddy soil is 1%-3%, while the organic matter content of dryland soil is lower than that of paddy soil, accounting for 31. 2% if less than 1% [1]. The black soil area in northeast China is one of the most significant commodity food bases, with a grain commodity rate as high as 70%. In recent decades, due to the lack of guidance of agricultural science and technology by farmers, long-term unbalanced fertilization has continued to deepen the damage to the land, and the degradation of the black soil is deepening. The black soil layer is losing at a rate of 0. 3-1cm per year [2]. Similarly, the situation of red soil mainly distributed in the south of China is not optimistic. In

China, the red soil is mainly distributed in south China, east China and central China, with an area of 2.18 million km<sup>2</sup>, accounting for 27% of the total cultivated land [3]. Due to natural reasons and unreasonable development and utilization, water and soil loss, soil acidification, soil fertility declines and other phenomena in the red soil region are serious, resulting in serious soil degradation and limited production potential. It seriously hinders the development of agriculture in red soil area. Therefore, soil improvement has become an important topic related to national livelihood. In the face of serious soil crisis, we urgently need a technology that can effectively repair without damaging soil fertility and ecological environment functions. The biochar technology perfectly meets the above requirements, not only can effectively repair soil, but also can be applied to the treatment of large areas of contaminated agricultural soil. With dual advantages in technology and economy, it is one of the important methods of soil remediation.

It has been proven that biochar can make a difference to related fields like soil improvement and greenhouse gas emissions. Many scholars at home and abroad have devoted themselves to the research of biochar in these roles, and have made significant progress. Soil bulk density is an indicator that can be used as a measure of soil quality. During the pyrolysis process of biochar preparation, some compounds volatilize and leave a large number of pores, which makes the biochar have a large specific surface area. The pakchoi can be used as the test crop, and the results of the experiment showed that when the volume ratio of biochar added into the soil gradually increased, the soil density decreased obviously and gradually [4]. The pH of the soil added with biochar will increase, which has formed a consensus in the existing studies. Reducing the H<sup>+</sup> in the soil can increase the soil pH, and the weak acid radicals such as CO<sub>3</sub><sup>2-</sup>, HCO<sub>3</sub><sup>-</sup>, SiO<sub>3</sub><sup>2-</sup> in the biochar can be combined with the H<sup>+</sup> in the soil solution through the hydrolysis reaction, resulting in an increase in the soil pH. The organic functional groups such as carboxylate, carboxyl, ether bond, and hydroxyl generated in soil can also absorb H<sup>+</sup> from soil.

The main ways of soil carbon sequestration can be attributed to two aspects: increasing the input of organic matter and reducing the decomposition of soil carbon. The added biochar is beneficial to the soil microorganisms such as increasing soil microbial biomass, microbial activity and soil respiration as well as soil enzyme activity, so as to achieve the effect of significantly increasing the mineralization rate of soil organic carbon. Rondon et al. added biomass char to pasture and soybean soil and found that the methane production process in pasture and soybean soil was completely inhibited [5]. It was speculated that the reason was that the improvement of aeration conditions influenced to the structure of high-carbon soil functional microbiologic population.

This article mainly summarizes the effects of biochar application on black soil and red soil by analyzing the changes of biochar application on the physical and chemical indicators of black soil and red soil. The study finds out that the application of biochar increases the pH of the black soil, and the pH under the treatment of high biochar application is always higher than that under the low application of biochar. The organic matter in black soil increases significantly and the C/N ratio also shows an overall upward trend with the rise of biochar application. The application of biochar promotes the transfer of carbon and nitrogen nutrients to the soil aggregate in the black soil, and effectively improving the soil carbon fixation capacity of the aggregates and the redistribution of organic carbon and nitrogen. Biochar also reduces soil bulk density. Besides, biochar increases the adsorption of inorganic nitrogen in black soil and reduces the substrate for nitrification and denitrification to generate N<sub>2</sub>O. The large specific surface area and loose and porous characteristics of biochar help the soil to absorb a large amount of CH<sub>4</sub>, providing carbon source for methanotrophs, promoting the oxidation of CH<sub>4</sub> in the soil, and reducing the emission of CH<sub>4</sub> to the atmosphere. Therefore, under certain conditions, the application of biochar can suppress the emission of greenhouse gases in the black soil, and with the rise of the biochar application, the emissions of N<sub>2</sub>O and CH<sub>4</sub> decrease significantly. For red soil, the application of different levels of biochar has different influence on the pH of red soil. The application of 2% and 4% biochar can significantly increase the pH of red soil [6]. Biochar also increases the soil organic matter and soil moisture, improving soil nutrient retention, promoting the growth of soil microbial community, accelerating the turnover and

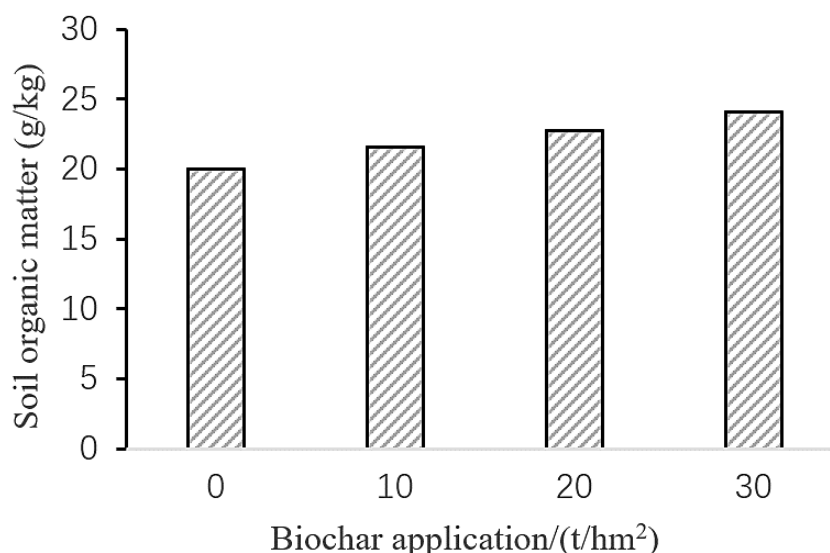
renewal of soil organic matter, and improving the productivity of red soil. The soil bulk density reduces obviously as well. Adding biochar to red soil can inhibit N<sub>2</sub>O emission, but the inhibition effect fluctuates with the increase of biochar and soil N<sub>2</sub>O emission increases at first and then decreases.

## 2. The effect of biochar on soil physicochemical properties

### 2.1. The effect of biochar on red soil

The pH of red soil is 5.0-5.5 and the organic carbon content is usually below 20 g·kg<sup>-1</sup>. The total nitrogen content is 1.92 g·kg<sup>-1</sup>. The red soil structure has strong dispersibility and is not easy to flocculate and also has poor water stability [7]. However, because of the rich iron-aluminum hydroxide colloids, its temporary microaggregates are better. The cation exchange capacity of red soil is not high, showing strong fixation of phosphorus [8]. Generally, the organic matter of red soil is low and the ability to retain fertilizer and water is poor, which is not conducive to growth of crop.

Biochar is widely used in soil improvement, pollutant degradation, soil carbon sequestration and emission reduction because of the rich surface functional groups, developed pore structure and huge specific surface area. The pH of the red soil is determined by the base ions. The biochar contains alkaline groups that can neutralize the protons in the red soil and more base ions, which exchange protons and aluminum in the soil after entering the soil, reducing their concentration, and then increasing the base saturation and pH of the red soil. And the pH of red soil increases with the rise of biochar application. Compared with the red soil without biochar, the soil pH was significantly increased by 46.1% when the application of biochar reached 30 t/hm<sup>2</sup> [9]. Biochar has light weight, porosity and low bulk density, so when it is added to the soil, it can loosen the soil layer and reduce the soil bulk density from 1.15 g/cm<sup>3</sup> to 0.99 g/cm<sup>3</sup> [6].



**Figure 1.** Comparison of soil organic matter under different levels of biochar application [9]

With the rising levels of biochar addition, soil organic matter gradually increases and the difference is significant among different treatments, as shown in Figure 1. Among them, the treatment with biochar application of 30 t/hm<sup>2</sup> has the largest increase in soil organic matter, which is 20.4%, 11.5% and 5.8% higher than those without biochar application, biochar application of 10 t/hm<sup>2</sup> and 20 t/hm<sup>2</sup>, respectively [9]. The soil organic matter also changes with the biochar prepared at different temperatures and time, as shown in Table 1. In contrast with the treatment without biochar (CK), the treatments of rice straw (RS) and rice straw biochar (RSB300, RSB400, RSB500) prepared at 300 °C, 400 °C and 500 °C could significantly increase the total organic carbon (TOC). But with the increase of cultivating time, the content of TOC in RS treatment decreases significantly (P<0.05), while there is no significant change in other treatments. The ratio of the total organic carbon (ΣTOC) of each

component after grouping to the measured TOC of soil before grouping (ie,  $\Sigma\text{TOC}/\text{TOC}$ ) is 96.5%-102.1%, indicating that the recovery rate of organic carbon after grouping is high,  $\Sigma\text{TOC}$  can be used to characterize the change of total organic carbon in the tested soil [10]. Biochar raises the organic matter in red soil, increasing soil moisture, improving soil nutrient retention, promoting the growth of soil microbial community, accelerating the turnover and renewal of soil organic matter, and improving the productivity of red soil. In the carbonization process, biochar converts unstable aliphatic compounds in rice straw into more stable aromatic carbon. The higher the pyrolysis temperature, the higher the proportion of stable organic carbon in biochar, and the less likely it is decomposed in soil. The loose porous structure of biochar can adsorb soil organic carbon and form a stable complex, thereby increasing the sequestration of soil organic carbon.

**Table 1.** Effects of biochar on the total organic carbon of reddish paddy soil [10]

Treatment	0 d			30d			120d		
	$\Sigma\text{TOC}$ (g/kg)	TOC (g/kg)	$\Sigma\text{TOC}/\text{TOC}$	$\Sigma\text{TOC}$ g/kg	TOC g/kg	$\Sigma\text{TOC}/\text{TOC}$	$\Sigma\text{TOC}$ g/kg	TOC g/kg	$\Sigma\text{TOC}/\text{TOC}$
CK	10.4±0.1	10.7±0.1Ab	0.978	10.5±0.1	10.3±0.1Ac	1.013	10.1±0.2	10.0±0.1Ad	1.010
RS	20.0±0.1	20.3±0.3Aa	0.986	17.0±0.2	17.1±0.6Bb	0.998	14.5±0.5	14.4±0.4Cc	1.008
RSB300	20.7±0.2	20.3±0.1Ab	1.019	19.4±0.2	19.0±0.4Aa	1.021	18.6±0.2	18.9±0.2Aab	0.980
RSB400	20.2±0.2	20.2±0.7Aa	0.995	18.9±0.2	18.9±0.4Aa	1.002	17.7±0.6	18.4±0.5Ab	0.965
RSB500	20.6±0.3	20.5±0.3Aa	1.006	19.6±0.3	20.0±0.3Aa	0.983	19.5±0.2	19.8±0.1Aa	0.984

The addition of organic rice straw can significantly and continuously increase the cumulative emissions of  $\text{CH}_4$  and  $\text{CO}_2$  in the red soil of paddy fields, as shown in Table 2. Compared with the CK treatment, the cumulative emissions of  $\text{CH}_4$  and  $\text{CO}_2$  in the red soil of the paddy field in the RS treatment increases by 3459.4 times and 5.8 times at 30 days of cultivation, and the cumulative emissions at 120 days increases by 109.0% and 36.3% compared with those at 30 days. Compared with the CK treatment, after 30 days of cultivation, the cumulative  $\text{CO}_2$  emissions from the red soil of the paddy fields in the RSB treatments decreases by 28.5%-33.7%, but the cumulative  $\text{CH}_4$  emissions in the RSB300 and RSB400 treatments increases by 188.5% and 32.7% respectively. And after 120 days of cultivation, the cumulative  $\text{CO}_2$  emission in red soil of paddy field decreases by 16.3%-16.6%, while the cumulative emission of  $\text{CH}_4$  in RSB300 and RSB400 treatments increases by 218.0% and 84.7% respectively. The emission of  $\text{CO}_2$  is mainly concentrated in 0-30 d. Due to the strong activity of methanogens in neutral or alkaline environments, the input of biochar improves the acidic conditions of red soil to a certain extent, stimulating the production of methanogens or inhibiting the activity of methanogens, resulting in the accumulation of  $\text{CH}_4$ , so  $\text{CH}_4$  emission in red soil increases [6]. Adding biochar into soil can create an environment conducive to the survival of microorganisms. The activity of microorganisms enhances, soil respiration increases and the pH of soil increases, which enhances the activity of nitrifying bacteria and denitrifying bacteria, resulting in an increase in the rate of microbial respiration.

**Table 2.** Changes of the cumulative emissions of CH<sub>4</sub> and CO<sub>2</sub> [10]

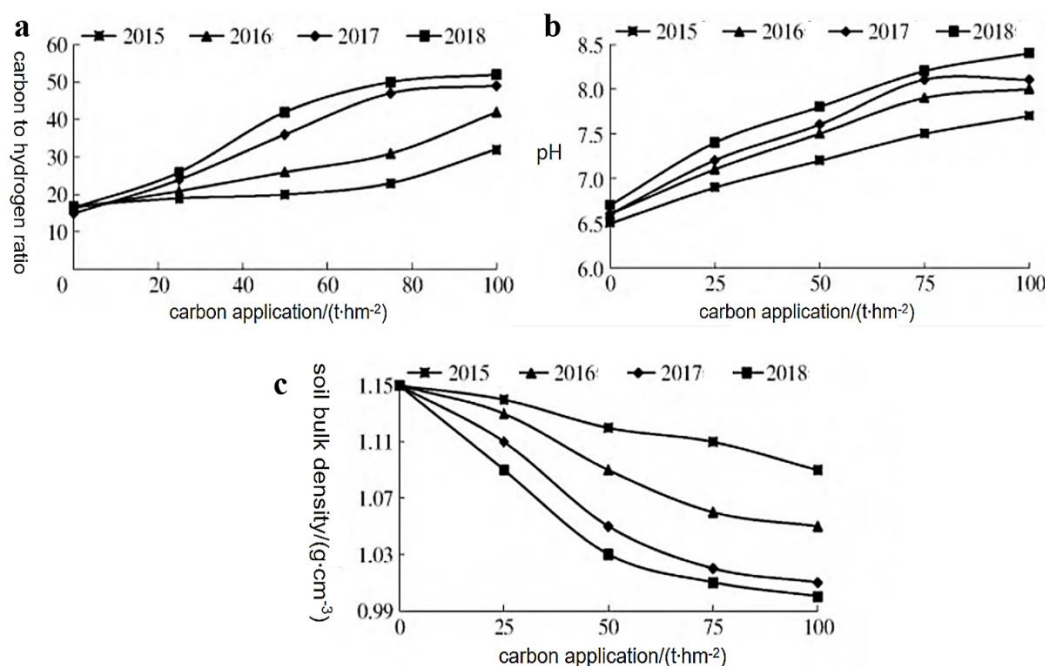
Treatment	0-30 d		0-120 d		0-30d/0-120 d	
	CH <sub>4</sub> /(μg/kg)	CO <sub>2</sub> /(mg/kg)	CH <sub>4</sub> /(μg/kg)	CO <sub>2</sub> /(mg/kg)	CH <sub>4</sub> /%	CO <sub>2</sub> /%
CK	12.3±0.3Bb(c)	8.7±0.4Bb(a)	17.3±0.3Ab(c)	12.4±0.6Ab(a)	71.1	70.3
RS	42608.0±525.6Ba	59.2±3.6Ba	89050.4±384.8Aa	80.7±4.9Aa	47.8	73.4
RSB300	35.5±0.8Bb(a)	5.8±0.0Bb(b)	55.0±2.6Ab(a)	10.4±0.1Ab(b)	64.5	55.7
RSB400	16.3±0.6Bb(b)	6.1±0.0Bb(b)	32.0±1.5Ab(b)	10.4±0.1Ab(b)	51.1	59.0
RSB500	12.7±0.2Bb(c)	6.3±0.1Bb(b)	18.7±0.2Ab(c)	10.4±0.1Ab(b)	67.7	60.3

Adding biochar to red soil can inhibit N<sub>2</sub>O emission, but the inhibition effect fluctuates with the increase of biochar and soil N<sub>2</sub>O emission increases at first and then decreases. Soil N<sub>2</sub>O emission is the result of nitrification and denitrification. The use of biochar leads to the decomposition of soil organic carbon as well as the increase of soluble carbon, which provides sufficient substrates for microorganisms in the process of nitrification and denitrification. The number and activity of microorganisms increase, making soil emissions more efficient and soil emits more N<sub>2</sub>O. The reason for the reduction of N<sub>2</sub>O emissions in the later stage may be that the high input of biochar causes soil C/N imbalance, hindering microbial activity, slowing down the decomposition of organic matter, and inhibiting soil N<sub>2</sub>O emissions. Meanwhile, the large specific surface area and high porosity of biochar increase the adsorption of inorganic nitrogen and reduce the substrate for nitrification and denitrification to generate N<sub>2</sub>O.

## 2.2. The effect of biochar on black soil

The climate in northeast China is relatively cold, so the lush vegetation in meadows and grasslands peels off and corrodes which gradually accumulates into a thick layer of humus, eventually formed a fertile black soil layer. However, due to the long-term high-intensity development and utilization as well as inappropriate agronomic measures, the function of black soil was seriously damaged so that the organic matter was reduced, which in turn affected the food production and green development of agriculture in northeast China. Most studies have shown that biochar has significant effects on soil improvement, the conservation of soil and water and so on. For instance, it can reduce soil bulk density and increase soil porosity to improve soil water retention and increase soil organic carbon content. In that, soil carbon-nitrogen ratio, crop moisture, utilization and production will increase. The pH of the black soil is 5.7-6.8, the organic carbon content is 30-60 g·kg<sup>-1</sup>, and the total nitrogen content is 10-20 g·kg<sup>-1</sup> [11]. The microstructure of the black soil is spongy, the structure is loose, and there are also many dendritic pores. The humus of black soil is mainly combined with calcium but the humus combined with iron and aluminum is less than 30%. The combined humus can form stable organic-inorganic complexes and water-stable aggregates. Its cations are mainly calcium and magnesium, and the exchange capacity can reach 30-45 centimoles (+)/kg, and the fertilizer has a strong ability of retention [11]. Wei et al. took the sloping farmland in the black soil area as the research object, selected the main food crop maize in the northeast region as the experimental crop, and applied biochar to the black soil for 4 consecutive years [12]. The variation law of yield and other indicators provides a scientific basis for the efficient utilization of black soil resources. The experimental soil is meadow black soil, and there are the basic properties: total organic carbon mass ratio 34.83 g/kg, total nitrogen mass ratio 1.11 g/kg, total potassium mass ratio 0.45 g/kg, total phosphorus mass ratio 0.35 g/kg. The pH value is 6.3, and the bulk density is 1.15 g/cm<sup>3</sup>. The corn variety is Demeiya No. 1, and the corn stalk was pyrolyzed at a high temperature of 400-500 °C under anaerobic conditions. There are its physical and chemical properties: the mass ratio of total organic carbon is 70.21 g/kg, the mass ratio of total nitrogen is 13.97 g/kg. The mass ratio of total potassium was 2.24 g/kg, the mass ratio of total phosphorus was 34.55 g/kg, and the pH value was 9.14. Before sowing of corn every year, the biochar was fully mixed with 0-20 cm plough layer soil, and the ridges were allowed to stand for 7 days [12].

By applying biochar to black soil year after year, a line graph was made by measuring soil bulk density, carbon-nitrogen ratio, and pH value under different carbon application rates each year. As shown in Figure 2, it can be seen from the figure that the soil bulk density has been decreasing with the increase of carbon application rate in the same year, and it is generally most obvious when the carbon application rate increases from 25 t/hm<sup>2</sup> to 50 t/hm<sup>2</sup>. The decrease in soil bulk density is due to the characteristics of light weight, porosity and low bulk density of biochar, which can loosen the soil layer and effectively reduce the soil bulk density when applied to the soil.



**Figure 2.** Change curve of soil physical and chemical properties [12]

On the contrary, the carbon-nitrogen ratio and pH value increases with the increase of carbon application rate. The value of pH value increased in different gradients of carbon application rate was relatively balanced, and the increase of carbon-hydrogen ratio showed slight differences with different years. The change of pH value is stemmed from the biochar is alkaline, and the reason may be that its ash material contains Na, Ca, Mg and other alkali metal elements as well as the surface is loaded with basic functional groups, which changes the acidity and alkalinity of soil.

**Table 3.** Greenhouse gas emissions per unit of production by treatment [13]

Treatment	CH <sub>4</sub>	N <sub>2</sub> O	CH <sub>4</sub> of unit output	N <sub>2</sub> O of unit output
DB0N1	247.65	0.32	40.44	0.05
DB1N1	226.65	0.29	35.97	0.05
DB2N1	170.33	0.21	22.21	0.03
DB3N1	148.25	0.23	21.07	0.03
DB0N2	299.05	0.43	36.49	0.05
DB1N2	281.69	0.40	34.03	0.05
DB2N2	190.44	0.32	20.55	0.03
DB3N2	178.03	0.28	21.02	0.03
FB0N1	549.40	0.25	93.47	0.04
FB1N1	522.06	0.23	86.47	0.04
FB2N1	384.76	0.17	53.56	0.02
FB3N1	327.06	0.20	47.72	0.03
FB0N2	639.87	0.30	79.13	0.04
FB1N2	607.91	0.27	74.73	0.03
FB2N2	452.24	0.20	51.80	0.02
FB3N2	267.77	0.16	30.39	0.02

The map based on measuring the unit yield and total CH<sub>4</sub> and N<sub>2</sub>O emissions of rice was made under shallow dry and wet irrigation mode and the conventional flooding irrigation mode [13]. As shown in Table 3, it can be seen that under the same irrigation mode and nitrogen fertilizer application, the emissions of CH<sub>4</sub> and N<sub>2</sub>O generally decrease with the increase of biochar application.

N<sub>2</sub>O emission of soil is due to the nitrification and denitrification, the large specific surface area and high porosity of biochar increase the adsorption of inorganic nitrogen as well as reduce the substrate for nitrification and denitrification to generate N<sub>2</sub>O. The application of biochar to paddy fields can inhibit the emission of N<sub>2</sub>O for two main reasons: First, biochar can fix NH<sub>4</sub><sup>+</sup>-N and NO<sub>3</sub>-N in the soil through physical adsorption [14]. Second, biochar affects soil nitrification and denitrification colony structure and abundance and the activities of related enzymes, as well as the mutual conversion between organic nitrogen and inorganic nitrogen. In addition, the physical adsorption of biochar itself can inhibit NO emission, improve cation exchange capacity, increase the adsorption of mineral nitrogen in paddy soil, reduce the substrate for denitrification, and reduce N<sub>2</sub>O generation. Meanwhile, the application of biochar increased the porosity of the paddy soil and increased the content of O in the soil, so that NO and O<sub>2</sub> could react rapidly. In addition, the biochar had a high carbon-nitrogen ratio, which inhibited denitrification. Meanwhile, the microbial transformation of N is also limited, which inhibits the emission of NO.

The main reasons why biochar affects CH<sub>4</sub> emissions from paddy fields include: biochar affects soil moisture content, increases soil O<sub>2</sub> content and Eh value, and changes the supply of carbon and nitrogen sources required by microorganisms. Soil moisture is one of the key factors affecting CH<sub>4</sub> emissions from paddy fields. Usually, soil O<sub>2</sub> content, CH<sub>4</sub> diffusion, activity of CH<sub>4</sub>-producing bacteria and CH<sub>4</sub>-oxidizing bacteria are all affected by soil water content. When the soil moisture in the paddy field is low, the CH<sub>4</sub> produced is oxidized by methanotrophs, resulting in a reduction in emissions; when the soil moisture is high, the organic matter will undergo anaerobic decomposition, resulting in a large amount of CH<sub>4</sub> emissions. It is related to the change of soil pH value. Methanogens are more active in neutral or alkaline environments. The input of biochar relieves soil acid conditions to a certain extent, stimulates methanogens or inhibits the activity of methanogens, causing accumulation of CH<sub>4</sub> [13].

### 3. Conclusion

It was found that the application of biochar had the same effect on the organic carbon content and C/N ratio of the two soils, but the index of black soil increased more significantly. The change trend of soil bulk density and pH was also consistent with the application of biochar, and the difference was not significant. The effects of biochar on greenhouse gas emissions were different between the two soils. In recent years, under the background of emphasizing green development and ecological priority, China has paid more attention to soil restoration. Ecological restoration of degraded soil is a major problem and arduous task that China urgently needs to solve. In short, soil remediation is a systematic complex project and a long-term arduous task, which requires not only technical support but also policy guidance. Balancing production development and soil environmental protection is the fundamental way to solve the problem of soil degradation. What we need to do is not only to repair the damaged soil, but also to improve people's awareness of soil protection, promote the transformation of traditional agriculture, increase investment in science and education in farming areas, and protect soil health while promoting farmers' economic income.

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