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Advances in research on effects of biochar on soil nitrogen and phosphorus

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Abstract. In the context of global research, soil non-point source pollution is becoming more and more severe. Biochar is used as a soil amendment to repair soil. Therefore, research on biochar has received extensive attention. According to relevant literature reports, biochar has strong adsorption performance, and according to its nature, it can improve the availability of nitrogen and phosphorus in crops and fix nitrogen and phosphorus in soil. Also, biochar can also improve soil structure and reduce the migration of N and P with soil media. The research mechanism of biochar is distinct. The article cites the results of the majority of researchers and explains the effects of different biochars. Biochar has a certain promoting effect on nitrogen, phosphorus adsorption, conversion and leaching. In the future, we should strengthen the prospect of biochar in the treatment of soil environment and sustainable development of the environment.

1. Introduction

With the increase of population and the increase in food demand, the problem of agricultural non-point source pollution has become more and more serious ^{[1]-[2]}. Chinese scholars have defined agricultural non-point source pollution as the excessive application of chemical fertilizers, pesticides and other factors in the planting industry, as well as the disorderly discharge of livestock and poultry manure in the aquaculture industry, exceeding the nutrient load of the farmland, and the emergence of nutrients such as nitrogen, phosphorus and potassium. Mentioned above nitrogen, phosphorus and potassium lefe in the soil caused soil pollution ^{[3]-[5]}. Most agricultural systems have limited ability to supply nitrogen and phosphorus to crops ^{[6]-[7]}. Many farmers in China have increased the growth of crops, using a large amount of nitrogen and phosphate, causing non-point source pollution in some areas and bringing indisputable soil environment. Researchers at home and abroad have found that biochar has a good adsorption effect ^[8].

Biochar is a carbon-rich, stable, solid substance^[9], such as wood^[10], manure^[11], sugar cane^[12], straw^[13] and other plants, usually under low oxygen or anoxic conditions, at relatively low temperatures (400~700 °C), thermal decomposition of organic compounds^{[14]-[16]}. It has high stability, large specific surface area, rich pore structure and strong adsorption capacity^{[17]-[18]}. Biochar has been widely applied, because of its simple preparation and low cost^{[19]-[21]}.

Therefore, combined with the current serious problem of agricultural non-point source pollution, according to the performance of biochar, as a soil improver, improve crop yield, and have the potential to improve nitrogen and phosphorus cycles in soil-plant systems^{[22]-[25]}. This paper mainly studies the absorption of nitrogen and phosphorus in soil by different biochar and the transformation mechanism of nitrogen and phosphorus.



2. Effect of biochar on soil nitrogen and phosphorus adsorption

2.1 Effect of biochar on soil nitrogen adsorption *Submit your manuscript electronically for review*

Biochar is prepared by pyrolysis of the material, and the pore structure of the prepared biochar will be different due to the pyrolysis temperature in the pyrolysis process. The researchers characterized biochar by SEM and FTIR techniques^[26], the higher the temperature, the larger the pore structure of biochar^{[27]-[28]}. Different biochars will have different results for nitrogen adsorption.

Suogufang et al.^[29] research shows that under the same initial conditions, the amounts of rice husk charcoal, pecan shell charcoal and bamboo charcoal were 23.79 mg•g⁻¹, 13.00 mg•g⁻¹ and 17.60 mg•g⁻¹, respectively. It indicates that rice husk charcoal has the best adsorption effect on nitrogen. The three kinds of biochar are alkaline, which is because biochar contains more base ions (such as calcium, sodium, magnesium, potassium, etc.) and basic groups^[30]. pH values of different biochars may be different because the mineral components in them will contribute differently to alkalinity^[31].

Yan-Hong Jiang et al.^[32] used magnesium chloride (MgCl₂) as a modifier to produce biochar from different raw materials. By comparing the specific surface areas of 6 biochar samples, the surface area of cassava straw biochar was the largest, while Chinese fir straw Biochar has the smallest surface area. Related analysis shows that the adsorption capacity of NH₄⁺-N is related to the specific surface area; Therefore, the larger the specific surface area, the stronger the surface energy adsorption, resulting in a significant adsorption effect^{[32]-[33]}. Kizito S et al.^[34] showed that the fixed carbon content, conductivity and pH of wood biochar are higher than that of rice husk biochar, wood contains more cellulose and hemicellulose, and pyrolysis at high temperature (>500°C), the constituents are reduced to carbon, so the fixed carbon content in wood biochar is higher^{[35],[36],[37]}. Wang B et al.^[38] used biochar to adsorb nitrate nitrogen (NO₃⁻-N). The results showed that the NO₃⁻-N adsorption of corn stover biochar was the highest, 0.929 mg•g⁻¹, while larch biochar NO₃⁻-N has the lowest adsorption capacity of only 0.578 mg•g⁻¹. Li-Jun WU^[39] and others found that corn stover and corn cob biochar showed good adsorption to nitrate nitrogen.

MP Sika et al.^[40] found that the adsorption process of NO₃⁻-N by biochar can be well fitted by the Freundlich equation. The FTIR and XPS spectra indicate that the oxygen-containing functional groups on the surface of biochar (-OH, -C=O, -O-) participate in the adsorption process. Combined with the distribution of surface elements of biochar, hydrogen bond formation and metal bridge bonding are the major mechanisms of biochar adsorption to NO₃⁻-N. The adsorption kinetics of NO₃⁻-N by biochar is mainly affected by the preparation materials and conditions, and most of them conform to pseudo-first-order kinetics or pseudo-second-order kinetic models^{[41]-[42]}.

Therefore, these antonymous observations of nitrogen adsorption may be caused by different physiochemical characteristics (e.g. chemical composition, molecular structure, surface area) of biochar^{[43]-[45]}, and at the same time, adsorption of different forms of nitrogen by biochar. The amount is different, and biochar promotes the adsorption of nitrogen.

2.2 Effect of biochar on soil phosphorus adsorption

Hale et al.^[46] found that biochar has no adsorption capacity for phosphorus, while the results of Chintala et al.^[47] are the opposite. Related studies have shown that the adsorption capacity of biochar for soil phosphorus is affected by many factors such as raw material properties, pyrolysis time and temperature. Ngatia et al.^[48] using a mixture of 10% biochar and 90% sand, the results showed that with the increase of pyrolysis temperature of biochar, the amount of P adsorption increased (P<0.0001), and the P effectiveness decreased (P<0.0001). However, the optimum phosphorus adsorption is a unique material for switchgrass, indicating phosphorus desorption between 200 and 550 °C. The order of phosphorus adsorption is Pueraria> switchgrass> Chinese tallow. With the increase of corn stover biochar addition, the adsorption rate constant of nitrogen and phosphorus in dark brown soil increased, the saturated adsorption capacity of nitrogen and phosphorus increased, and the fixation ability of nitrogen and phosphorus increased^[49].

Therefore, the adsorption of phosphorus by biochar on soil is affected by many factors. The mechanism of adsorption of nitrogen and phosphorus by biochar is affected by many factors such as soil physical and chemical properties, organic matter content and biochar.

3. Effect of biochar on nitrogen and phosphorus conversion

3.1 Effect of biochar on nitrogen conversion

Biochar utilizes its pore structure to change the basic physical and chemical properties of the soil and affect the conversion of nitrogen in the soil. Nitrogen (N) is one of the most important elements of plant growth and productivity^[50]. In particular, soil inorganic nitrogen (SIN) is an important nitrogen source for plants because plants absorb inorganic nitrogen directly through the rooting system^[50]. Nitrogen conversion mainly includes nitrogen fixation, nitrogen mineralization, ammonia volatilization, nitrification and denitrification^[51].

Adding biochar material to alkaline sandy soil can significantly reduce the volatilization of NH_3 and convert it to NO_3^- by nitrification. This process can be enhanced by increasing the rate of application of biochar produced at higher pyrolysis temperatures. The largest of the switchgrass biochar produced at 800 °C (10.47 mg • g⁻¹), 400 °C leeches biochar (3.82 mg • g⁻¹) and bio-biosolids (43.29 mg • g⁻¹) NH_4^+ retention capacity. At the same time, biochar was found to be limited (switchgrass and leeches) and negative (biosolids) to retain NO_2^- and NO_3^- . It has been found that cation exchange capacity (CEC) and morphological characteristics (such as porosity) are the main factors affecting the adsorption of biochar NH_4^+ ^[52]. Some studies have shown that NH_4^+ and NO_3^- are quite adsorbed with biochar. For example, it has been reported that biochar produced at 600 °C in Brazilian pepper and peanut shells can significantly reduce NH_4^+ (34.0-34.7%) and NO_3^- (14.0-34.0%)^[53].

Considerable adsorption of NH_4^+ was observed, while limited adsorption or even release of NO_3^- and NO_2^- ^[53] was found in all tested raw materials and biochar. The effect on soil nitrogen transformation was consistent. The soil ammonium nitrogen content decreased gradually, while the nitrate nitrogen content increased gradually. The NH_4^+ -N content of treated soil with 1%, 2% and 5% biochar decreased compared with the control. 13.3%~16.0%, 18.6%~28.5%, 51.1%~68.8%, NO_3^- -N content increased by 6.4%~13.3%, 12.9%~19.7%, 18.4%~22.7% compared with the control, which may be related to the increase in ammonia volatilization caused by the increase in soil pH after the addition of biochar^{[54]-[55]}.

Feifei et al.^[56] found that compared with no nitrogen fertilizer and nitrogen fertilizer treatment, the accumulation of NO_3^- -N in biochar treated soil is higher, the main reason is the soil pH, the number of ammonia-oxidizing bacteria, NO_3^- -N, microorganisms. Biomass carbon/nitrogen is significantly correlated.

3.2 Effect of biochar on phosphorus conversion

Phosphorus is one of the many elements necessary for plant growth and development^{[57]-[58]}, and it is also a major element in causing eutrophication of water bodies^{[59]-[60]}. Phosphorus in soil is mainly composed of inorganic phosphorus and organic phosphorus^{[61]-[62]}. The conversion of phosphorus by biochar is mainly through chemical action, and it is affected by many factors in this research process^[63]. Studies have shown that the woody structure of biomass releases phosphate during carbonization and becomes a direct source of phosphorus in the soil as biochar is added to the soil^[64]. The effect of biochar on the conversion of phosphorus in soil depends on the type of raw material and the preparation conditions of the biochar. The phosphorus content of biochar prepared from different materials is significantly different. For example, biochar made from rape straw and pea straw at the same temperature (350 °C), the phosphorus content after carbonization are 2.2, 16.6 g•kg⁻¹^[65], biomass of the same material, total phosphorus and phosphorus content of biochar, inversely proportional to the carbonization temperature^[66]. The addition of biochar can increase the solubility of phosphorus and promote the solubility of PO_4^{3-} in the soil. The application of biochar increases the available phosphorus content of the soil and increases the fertility of the soil^{[67]-[68]}.

4. Effects of biochar on soil leaching of nitrogen and phosphorus

Due to the influence of the research environment, some researchers used the indoor soil column simulation experiment to explore the effect of biochar on the leaching of nitrogen and phosphorus in the soil pond. Zhuorui et al.^[69] and other results showed that the addition of biochar in the soil could effectively reduce the leaching of TN and TP, the addition amount is 2%, 4%, 6% and 8% compared

with the control without biochar, TN The leaching loss was significantly reduced by 17.6%, 24.7%, 30.6% and 37.7%, respectively ($P < 0.05$), and the leaching loss of TP was significantly reduced by 26.0%, 12.0%, 15.7% and 19.7%, respectively ($P < 0.05$); The optimum amount of biochar added to soil TN and TP leaching was 8% and 2%, respectively. The application of biochar could effectively reduce the risk of leaching of TN and TP in the soil, and control nitrogen and phosphorus in vegetable soil.

Jihui et al. ^[70] have shown that the addition of the best-modified carbon in the soil can delay and reduce the leaching of nitrate nitrogen and available phosphorus. The addition amount is 2.5%, 5% and 10% with no added matter. Compared with the control^[70], the leaching loss of nitrate nitrogen was significantly reduced by 20%, 43% and 59%, respectively ($P < 0.05$), and the leaching loss of available phosphorus was significantly reduced by 45%, 59% and 75%, respectively ($P < 0.05$), indicating that the addition of modified biochar in the soil can effectively reduce the risk of leaching of soil nitrate-nitrogen and available phosphorus.

Yi et al. ^[71] have shown that the application of charcoal can significantly inhibit nitrogen leaching by 4%, 8% of biochar application decreased soil nitrogen leaching by 20.7% and 30%, respectively. When the ratio is 2%, the leaching of nitrogen has the opposite effect, and the soil nitrogen leaching amount is increased by 5.9%. Since biochar itself contains a large amount of nitrogen, it significantly increases the total nitrogen content in the soil, but has no effect on the content change of each soil layer, and reduces the content of alkali nitrogen in the soil.

Related literature reports that the effect of adding biochar on the phosphorus leaching loss of soil may depend on two aspects: on one hand, biochar itself has a strong adsorption and fixation effect on phosphate and soluble organic phosphorus, which is beneficial to the control of phosphorus. Leaching^[72]; on the other hand, the application of biochar increases the pH of the soil significantly, which may increase the availability of phosphorus, which is beneficial to promote phosphorus leaching^[73].

5. Conclusions and recommendations

In recent years, relevant scholars at home and abroad have made significant research on the biophysical properties of biochar to improve soil physical and chemical properties and promote the adsorption and transformation of nitrogen and phosphorus in soil.

However, there are certain deficiencies in the risk research of agricultural non-point source pollution. Future research on biochar can strengthen the following points:

- 1) The current research on agricultural non-point source pollution is not comprehensive enough, the adsorption and transformation of nitrogen and phosphorus in soil Research can improve crop growth. For better research, the establishment of a bio-carbon model for nitrogen and phosphorus in the soil boundary needs further exploration.
- 2) The effect of biochar on nitrogen and phosphorus is mainly in the soil field at this stage, but it should also be strengthened in water applications. Authors must convince both peer reviewers and the editors of the scientific and technical merit of a paper; the standards of proof are higher when extraordinary or unexpected results are reported.
- 3) The use of biochar in agricultural research and water eutrophication research and treatment process, the current research is in the short term, focusing on the future, should have greater research and development potential.

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