Biochar as a replacement of fertilizer for the sustainable agriculture: A review

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***Abstract*: Pesticide pollution and soil degradation are two major issues in the agricultural ecosystem. Biochar application is a promising method because it has been shown in numerous previous studies to be highly effective in increasing crop yield and enhancing pesticide degradation. In this section, we will look at the possibilities. Advantages of biochar in increasing fertilizer efficiency by increasing nutrient availability and soil fertility by improving nutrient retention and release. Its role in pesticide chemical degradation and biodegradation is also being studied. Biochar has a high surface area with many functional groups, a high cation exchange capacity, and a high stability. The influencing factors and mechanisms for nutrient retention by biochar are discussed (for example, feedstock, pyrolysis temperature, and application rate). Because laboratory experiments and field trials have different conditions, more research should be done on the long-term dynamic function of biochar.**

***Keywords*: Biochar, organic fertilizer, biodegradation, bioremediation**

Introduction

Fertilizer (e.g., nitrogen (N), phosphorus (P), and potassium (K)) and pesticide application in agricultural soil has grown increasingly intense as a strategy to boost crop yields. Fertilizer use in India, for example, has risen from 12.4 kilograms per hectare in 1969 to 175 kilograms per hectare in 2018, expanding at a 5.96 percent yearly rate [1]. And, in order to establish more sustainable agriculture systems and strengthen rural economies, fundamental reforms in agriculture management are required. Leaching losses of fertilizer and pesticide may occur during intensive application, causing soil fertility to deteriorate and pollution to occur. Furthermore, nutrient leaching from agricultural soils can reduce soil fertility, raise farming costs, hasten soil acidification, and lower crop yields [2]. Pesticides have a tendency to travel long distances and cross borders, and their ability to bioaccumulate in the food chain can represent a serious threat to human health and the environment [3]. On the one hand, in order to meet the high demand for food in some countries, people must urgently improve soil fertility and nutrient availability in order to increase crop yields; on the other hand, pesticide degradation is a critical goal for both soil management and environmental protection. Bioremediation is less dangerous, less expensive, and more socially acceptable than traditional remediation [4]. Some pesticides, however, such as organochlorine pesticides, are difficult to biodegrade in a short period of time. Furthermore, microorganisms are sensitive to environmental changes such as heat, desiccation, and ultraviolet radiation [5]. Moreover, the competition between different microbial species and other organisms that occurs in the soil is also a challenge. The efficiency of pesticide biodegradation could be drastically reduced under these conditions. Overall, if crop yields are to be increased, pesticide-polluted soil rehabilitation, and sustainable agriculture are to be attained, effective and low-cost solutions that can improve soil conditions, enhance microbial activity, and pesticide breakdown are required.

Pathogens, heavy metals, and medications can be found in manures and composts, which can lead to long-term contamination of agriculture. Furthermore, manures and composts have the potential to produce ammonia and methane, which can exacerbate global warming and cause major nutrient contamination in groundwater and streams. Biochar is a viable resource for soil fertility management since it is a renewable resource with economic and environmental benefits. Furthermore, Biochar containing ammonium, nitrate, and phosphate could also be used as a slow-release fertilizer to improve soil fertility [6,7].

Biochar is a carbon-rich solid made by heating biomass in the absence of oxygen. It has a porous carbonaceous structure, a functional group, and an aromatic surface. Slow pyrolysis, hydrothermal carbonization, flash carbonization, and gasification are the basic methods for producing biochar [8]. Biochar made from biomass pyrolysis can change the soil's physicochemical qualities [9], reduce gaseous nitrogen emissions [10], change soil nutrient availability [11], minimize nutrient leaching [12], and boost crop production [13]. Furthermore, biochar made from pig manure has the ability to degrade up to 90.6 percent of carbaryl [14]. Moreover, biochar improved soil microbial properties such as microbial abundance and activity, as well as mycorrhizal associations [15]. These investigations showed that biochar has a lot of potential in terms of preserving soil fertility, inactivating pesticides through abiotic breakdown, and speeding up pesticide biodegradation.

In this paper, we examine the potential benefits of biochar in improving fertilizer use efficiency by increasing nutrient availability and soil fertility by improving nutrient retention (i.e., decreasing nutrient leaching and gaseous nutrient emission) and release. Besides that, the mechanisms of biochar in soil fertility improvement were examined. We also discussed biochar's physical and chemical properties, present the factors and mechanisms that influence various biochar functions, and identify future prospects and knowledge gaps.

Properties of Biochar

Biochar's physical and chemical properties influence its adsorption properties. For example, increasing the acidic functional groups in biochar can increase NH_4^+ adsorption [16]. Biochar has a large specific surface area, a lot of oxygen-containing functional groups, and it's very stable [17]. Biochar's physicochemical properties are primarily determined by the feedstock and the pyrolysis temperature [18]. Many feedstocks, such as wood-chips, organic wastes, plant residues, and poultry manure, can be used to produce biochar [19]. The typical pyrolysis temperature ranges between 200 and 800C [20].

Surface Area

The specific surface area of biochar is significant because it aids in the adsorption of substances (such as heavy metals and organic compounds) [21]. Increasing the pyrolysis temperature can increase the specific surface area of biochar as well as the formation of micropores. The surface area of sugarcane bagasse biochar increased from 0.56 to 14.1 $m^2 g^{-1}$ when the pyrolysis temperature was raised from 250 to 600 °C [22]. Similarly, the surface area of soybean stover biochar produced at 700 °C was 420 $m^2 g^1$, which was significantly higher than that of biochar produced at 300 °C (6 $m^2 g^1$) [23]. One possible explanation is that the release of volatiles within the biochar increases as the pyrolysis temperature rises. Furthermore, the surface area of biochar is affected by the feedstock used. Biochar produced from bagasse and cocopeat had surface areas of 202 and 13.7 $m^2 g^1$, respectively. Furthermore, when compared to biomass, volatiles in biochar made from bagasse and cocopeat decreased by 87.1% and 70.1% respectively [24]. The release of volatile matter, primarily celluloses and hemicelluloses, during pyrolysis can increase the formation of vascular bundle structure in biochar, improving its specific surface area and pore structure [25]. In general, the influence of feedstocks and pyrolysis temperatures on biochar surface area can be attributed primarily to the release of volatile matter.

Cation exchange capacity (CEC) and pH values

The CEC measures biochar's ability to adsorb cations, which are essential nutrients for plants (e.g., $NH4^+$ and Ca^{2+}) [26]. Thus, a high biochar CEC can reduce nutrient loss from soil leaching. As the pyrolysis temperature increased from 200 to 550 °C, the CEC of cordgrass biochar increased from 8.1 to 44.5 cmolc kg-1, then decreased to 32.4 cmolc kg-1 [27]. Similarly, the CEC of sugarcane bagasse biochar rose from 6.40 cmolc kg-1 (pyrolyzed at 250 °C) to 9.66 cmolc kg-1 (pyrolyzed at 500 °C) before falling to 4.19 cmolc kg-1 (pyrolyzed at 600 °C) [22]. According to these comparisons, biochar produced at high pyrolysis temperatures (i.e., >500 °C) has a low CEC. The aromatization of biochar, as well as the disappearance of functional groups on biochar, have been attributed to the decrease in CEC at high pyrolysis temperatures.

The use of biochar can raise soil pH due to the pH of the biochar itself and by improving cation retention in the soil (e.g., $Ca^{2+,}$ $Mg^{2+,}$ and K^+). The pH of biochar produced at higher temperatures is higher due to the release of alkali salts from the organic matrix of the feedstock [23]. For example, when the pyrolysis temperature was increased from 300 to 600 °C, the pH value of biochar produced from corn straw increased from 9.37 to 11.32 [28]. The pH of swine manure biochar produced at 400 and 800 degrees Celsius was 7.60 and 11.54, respectively [29]. As a result, biochar with a high CEC and pH has a high potential for retaining NH4- and K-fertilizer and increasing their utilization efficacy.

Biochar stability

Although biochar is increasingly recognized as a valuable tool for long-term soil amendment (e.g., carbon sequestration, nutrient retention, and pesticide-contaminated soil remediation), its long-term environmental stability remains unknown. As previously stated, biochar stability is primarily determined by the temperature of pyrolysis and the feedstock. According to one study, certain types of biochar can degrade relatively quickly in some soils, possibly depending on the conditions under which they were produced, implying that pyrolysis could be optimized to produce a more stable biochar [30]. In general, increasing pyrolysis temperatures can improve biochar stability. For example, increasing the pyrolysis temperature from 350 to 550 °C significantly increased the stability of sugarcane bagasse biochar [31]. In fact, the amount of recalcitrant carbon substrates affects biochar stability.

Biochar as a nutrient source

Role of Biochar as a fertilizer

Organic matter and inorganic salts, such as humic and fluvic-like substances, as well as available N, P, and K, can be used as fertilizer and assimilated by plants and microorganisms. At 300 °C, Lantana camara biochar contained available P (0.64 mg kg^1), available K (711 mg kg^1), available Na (1145 mg kg^1), available Ca (5880 mg kg^1), and available Mg (1010 mg kg^1) [32]. Similarly, fresh biochar had the potential to increase nutrient availability by releasing large amounts of N (23–635 mg kg^{-1}) and P (46–1664 mg kg^{-1}) [33]. As a result of these findings, biochar appears to have a high potential as a source of available nutrients. Although total N, P, and K in biochar may not always reflect actual nutrient availability to plants, available N, P, and K (e.g., ammonia (NH^{4+}) nitrate (NO^3), phosphate ($PO_4{}^3$), and K^+) may be related to total N, P, and K. Many recent studies assessed nutrient availability in biochar's using short-term column leaching experiments or kinetic models. Total N, P, and K in biochar could be used as an indirect indicator for selecting appropriate biochar in practice.

Factors influencing biochar nutrient content and availability

The feedstock source and pyrolytic temperature had a significant impact on the nutrient content of biochar. For example, in three woody and four herbaceous biochar's, N losses began around 400 °C and then half of the N was lost as volatiles around 750 °C [34]. However, the available P in biochar's produced at lower temperatures was significantly higher than in biochar's produced at high temperatures. Actually, lower temperature biochar's contained less crystallized P-associated minerals, which could explain the reasons. Furthermore, the total K content increased from 3.7 percent at 300 °C to 5.02 percent at 600 °C, while the available K (water-soluble) content increased as the pyrolysis temperature increased [35]. Furthermore, the composition of nutrient elements in biochar's produced from various feedstocks varies. For example, swine manure biochar produced at 400 °C contained high levels of N (3.2%) and P. (6.1%) [36]. The constituents of Arundo donax biochar produced at 400 °C were low in N (0.69%) and P (0.13%). Furthermore, at 350 °C, the ash content of biochar made from poultry litter (30.7%) was significantly higher than that of biochar made from pine wood chip (30.7%) [16]. The pH of the soil has a significant impact on the nutrient availability of biochar.

The emission of PO_4^3 and NH_4+ was pH-dependent, whereas the release of K^+ and NO_3 was not. Similarly, the initial Ca and Mg release from corn straw biochar was pH-dependent, increasing as pH decreased from 8.9 to 4.5 [37]. It is critical to consider the impact of application time on biochar nutrient release. Furthermore, high C mineralization and N immobilization of volatile matter in biochar by microorganisms may reduce nutrient release. In practice, these influencing factors may coexist when biochar is applied to soil. Lowering the pyrolysis temperature and pH may increase the availability of N and P, while higher pyrolysis temperature may increase K availability.

Potential of Biochar for increasing soil fertility

Biochar to improve efficiency of fertilizer

Improving crop yield by increasing fertilizer use efficiency is a viable option. In one study it was investigated about of green waste biochar on radish. And they discovered that using biochar did not increase radish yield in the absence of N fertilizer. However, in the presence of N fertilizer, radish yield clearly increased with biochar application, indicating that biochar could efficiently improve plant nitrogen utilization. For example, with a biochar application rate of 100 t ha^{-1}, the increase in radish yield in the presence of N fertilizer was 266% when compared to the control (the absence of N fertilizer). In the presence of N fertilizer (100 kg N ha^{-1}), however, the yield increase (percentage) increased from 42% at 10 t ha^{-1} to 96% at 50 t ha^{-1} of biochar application, when compared to the control [38]. Furthermore, biochar has been shown to increase maize grain yield by 28% and Ca, Mg, K, and P availability by 17%-600% in biochar-affected fields [13]. As a result, biochar is thought to have a high potential for improving plant fertilizer use efficiency by increasing nutrient availability in the soil.

Nutrient retention in biochar-treated soil

Biochar's heterogeneous composition means that its surface can have hydrophilic, hydrophobic, acidic, and basic properties, all of which affect the biochar's ability to adsorb soil solution components and hence fertilizer retention. Biochar, on the one hand, can improve nutrient retention through the adsorption process. For example, the total amount of NO_3, NH_4^+, and PO_4^3 in the leachates was reduced by 34.0%, 34.7%, 20.6%, and 34.3%, 14.4%, 39.1% respectively, using peanut hull and pepperwood biochar's generated at 600 degrees Celsius [39]. Furthermore, one study found that spartina spartina biochar prepared at 350°C may absorb 0.5 mmol g1 of K^+. As a result, biochar can be used to address nutrient deficiencies in soil [40]. N2O emissions were reduced by 80% with the use of biochar, according to one study [41]. Indeed, improved soil physicochemical features, such as increased porosity and water storage capacity, and decreased bulk density, may contribute to improved nutrient retention after biochar amendment. Overall, biochar offers a lot of promise for increasing fertilizer efficiency by reducing nutrient leaching and gaseous nitrogen losses.

Biochar, microorganisms, and fertility

Biochar has been found to change soil biological qualities as well as improve soil physicochemical properties. These modifications could improve soil structure by increasing organic/mineral complexes (aggregates) and pore spaces, as well as improve nutrient cycles by improving nutrient retention and immobilization and reducing nutrient leaching thus promote plant growth [42]. Furthermore, microbes such as rhizosphere bacteria and fungus may directly assist plant growth [43]. In conclusion, biochar-induced changes in microbial community composition or activity may have an impact on nutrient cycles, plant growth, and soil organic matter cycling. This section gives an overview of the effects of biochar qualities on the microbial community, such as organic and inorganic composition and surface properties.

Influence of biochar on microorganism's community

There is a growing interest in using biochar to control soil biota, and modest changes in soil biota caused by biochar application are also a source of worry. Some methods could explain how biochar affects soil microorganisms: (1) changes in food availability; (2) changes in other microbial populations; (3) changes in plant-microbe signaling; and (4) habitat creation and hyphal grazer protection. The soil food web has a significant impact on microbial characteristics. Furthermore, the quantity, quality, and distribution of organic matter had a significant impact on the trophic structure of the soil food web. Despite the fact that soil organic matter production is modest in comparison to other carbon cycle processes, its relative stability for microbial breakdown allows soil organic matter accumulation.

Biochar's effect on microbial abundance

According to one study, after adding 30 t ha^1 biochar, microbial abundance increased from 366.1 (control) to 730.5 gCg^1. Similarly, for the different preincubation times (2–61 days), microbial abundance rose by 5–56% as maize stover biochar rates increased (from 0 to 14%) [44]. The increased microbial abundance could be due to a variety of factors, including increased nutrition availability or labile organic materials on the biochar surface, improved habitat appropriateness and refuge, and improved water retention and aeration [45]. Microbial abundance can also be influenced by nutrient and carbon availability. With the different forms of biochar and the particular bacteria group, this influence differed substantially. The various demands of the plant may have resulted in symbiotic partnerships with biota created through varying nutrient supply. Similar arguments may apply to the effect of increased C supply in the rhizosphere due to exudation or root turnover, as well as C as an energy source for heterotrophic microbes [46]. As a result, the effect on microbial abundance varied depending on whether biochar additions were used in the rhizosphere or bulk soil. In nutrient-limited settings, on the other hand, microbial abundance may be increased due to increased nutrition availability after biochar application [47]. Some recent studies appear to show that the following factors can influence the impact of nutrient and carbon availability on microbial biomass: (i) existing nutrient and carbon availability in soil; (ii) the added amount of nutrient and carbon; and (iii) microorganism features. Microbial abundance may rise as microorganisms bind to biochar surfaces, making them less susceptible to soil leaching. The major processes of adsorption to biochar include hydrophobic attraction, electrostatic forces, and the formation of precipitates [48]. Furthermore, biochar with a well-developed pore structure may provide a home for microorganisms. By investigating pore habitats in biochar, bacteria and fungus may be better protected from predators or rivals [49,50].

Toxins and chemical signals that inhibit microbial development could be absorbed by biochar. Furthermore, high-temperature biochar's have been found to have greater adsorption on chemicals that are harmful to microbes [51]. Humidity may also have a significant impact on microbial abundance. Microorganisms would be stressed in soil that is subjected to periodic drying, causing them to go dormant or even die. Because of its huge surface area, biochar has a high-water holding capacity, which may encourage the growth of microbes. However, the original components and properties of biochar cannot be used to draw any further inferences. According to some theories, bacterial cells or growth-regulating chemicals may play a role in sorption.

Enhancing the remediation of pesticide-contaminated soil with biochar

Potential of biochar enhancing the degradation of pesticide in soil

Biochar has been shown to aid pesticide breakdown by soil microorganisms. On the one hand, with the addition of biochar, pesticide biodegradation may be influenced by both enhanced natural microbial activity in the soil and reduced pesticide bioavailability. Biochar has been shown in numerous studies to improve microbial living conditions, including modifying soil pH, raising soil organic matter, increasing soil water content, providing habitat, and lowering competition from other microbes, all of which increase microbial characteristics (e.g., microbial community composition, abundance, and activities) [52]. However, biochar addition can improve pesticide sorption in soil, lowering pesticide concentrations in the soil solution and decreasing pesticide bioavailability to microorganisms [53]. Chemical degradation and biodegradation, on the other hand, are the two main mechanisms for pesticide elimination in soil with biochar amendment. Since current pesticides are engineered to be quickly dissolved, chemical hydrolysis is a key path of chemical and abiotic degradation in soil. Some research has indicated that when soil is modified with biochar, pesticide hydrolysis can be catalyzed, which has been linked to the combined effects of higher pH, released dissolved metal ions, and active groups on mineral surfaces [54]. Overall, biochar addition could be a viable and effective way to improve pesticide bioremediation in damaged soils.

Chemical degradation of pesticide in biochar-amended soils

Because of its catalytic properties, biochar can accelerate pesticide hydrolysis in soil. For example, to assess the effects of hydrolysis on carbaryl degradation, researchers autoclaved experimental soils at 120 °C for 30 minutes and found that the breakdown rate increased from 44.3% for the unamended soil to 55.0 percent for the biochar-amended soil. The catalytic effects of biochar on pesticide hydrolysis, on the other hand, are dependent on a number of factors, including the feedstock, pyrolysis temperature, and application rate. At 350 °C, carbaryl hydrolysis rates for pig manure biochar and maize straw biochar were 55.0% and 52.8%, respectively [55]. Furthermore, at 350 and 700 °C, biochar made from pig manure can hydrolyze 59.1% and 90.6% carbaryl, and 21.2% and 63.4% atrazine, respectively [56]. However, according to one study [55], the hydrolysis rate of carbaryl reduced from 53.7% to 50.0% when the pyrolysis temperature of rice straw biochar was increased from 350 to 700 °C. Investigations into the biochar application rate yielded the opposite results. The following phenomena could be induced by a variety of changes caused by different biochar applications, such as pH, dissolved metal ions, active groups, and pesticide sorption.

The pH of a pesticide's chemical hydrolysis can have a significant influence. For example, base-catalyzed hydrolysis of the carbamate ester link in carbaryl, but atrazine is a fairly persistent herbicide that can be hydrolyzed in strong acidic or alkaline solutions [57]. As a result, while an increase in pH caused by biochar may help carbaryl hydrolysis, it does not always help atrazine hydrolysis. Furthermore, the buildup of nucleophiles on the surface of biochar can aid pesticide degradation. Furthermore, hydroxy groups on the biochar surface may operate as nucleophiles, and attached metal atoms on the biochar surface may coordinate a hydrolysable moiety by building complexes with pesticides, allowing water molecules to attack nucleophilic ally [58]. Furthermore, one study found that pesticide sorption could be increased in biochar-amended soil, lowering the concentration of free pesticide in the soil solution and potentially slowing the hydrolytic process and decreasing the breakdown rate. In fact, all of these factors should be considered when determining the pesticide hydrolysis rate. Overall, the catalytic effects of biochar could improve pesticide hydrolysis, but the increased pesticide sorption could diminish it [59].

Biodegradation of pesticides in soil treated with biochar

Biochar can influence pesticide biodegradation through affecting microorganism activity and pesticide bioavailability, as well as catalyzing pesticide hydrolysis. With a 0.5% application rate of pig dung biochar produced at 350 °C after 40 days of incubation, carbaryl breakdown efficiency rose from 55.0% to 75.0% in unsterile soil compared to sterile soil indicating an enhanced pesticide biodegradation [55]. Furthermore, the effect of biochar on pesticide biodegradation differed depending on the feedstock, pyrolysis temperature, and application rate. For example, one study found that using a 0.5% application rate, the enhancement of carbaryl biodegradation ranged from 19.5% to 27.3% for three biochar's pyrolyzed from rice straw, pig manure, and maize straw at 350 °C, and from 3.1% to 27.3% for maize straw biochar's produced at 350 and 700 °C, respectively [55]. Furthermore, with application rates of 0.5% and 5%, the increase of pig dung biochar formed at 350 °C ranged from 13.8% to 20.0% Biochar's impacts on microbial characteristics and pesticide bioavailability are largely determined by its qualities. Biochar with high levels of amorphous carbon and liquid organic matter might boost microbial activity since these chemicals are easily digested by microbes as food. The activity of native microorganisms can be greatly affected (usually decreased) by the change in soil pH generated by biochar treatment [60]. Furthermore, increased pesticide sorption after charcoal addition can reduce pesticide concentration in the soil solution, lowering pesticide bioavailability and biodegradation. According to one study, biochar inhibited microbial atrazine mineralization by interfering with the sorption and desorption processes, lowering atrazine bioavailability. As a result, pesticide sorption in biochar-amended soil could impact biodegradation [61].

Sorption of pesticides in soil treated with biochar

Pesticide sorption in soil treated with biochar can minimize pesticide mobility, volatilization, leaching, and plant uptake. However, as previously mentioned, the addition of biochar to the soil may improve pesticide sorption, lowering pesticide concentrations in the soil solution and pesticide bioavailability to microorganisms, reducing chemical and biodegradation of the pesticide. Though both biochar and soil may absorb pesticides, biochar was found to be more effective than soil at absorbing pesticides [62]. Pesticide sorption capacity on biochar is greatly influenced by biochar features such as organic carbon concentration, aromatic nature, specific surface area, and ash content [63]. For example, one study [56] found that carbaryl and atrazine adsorption was influenced by hydrophobic effects, pore-filling, and π-π electron donor-acceptor interactions. Furthermore, because some pesticides are weak bases and exist as neutral molecules, they can establish weak hydrogen bonds with carboxyl groups or the clay surface via their heterocyclic nitrogen atoms.

Biochar's negative impact on soil biodiversity

Depending on the biochar and soil type, the effects of biochar on the soil microbial community may be negative, null, or positive. Organic pyrolytic products that are harmful to soil microorganisms, such as phenolics and polyphenolics, may be present in biochar. According to one study, after applying biochar, mycorrhizae and total microbial biomass decreased [64]. According to one study, a decrease in microbial abundance and activity may be expected as a result of increased retention of toxic substances such as heavy metals and pesticides, as well as the release of pollutants from biochar such as bio-oil and polycyclic aromatic hydrocarbons. It is not possible to conclude that a specific biochar that is beneficial to one soil biota will also be beneficial to others [65, 66]. Several factors, including volatile matter, biochar properties, and salts such as Cl or Na, are most likely to blame for biochar's negative effects on soil biota. In one study it was found that after using biochar without washing procedures to remove organic and inorganic matter, clover plants' petioles withered and their leaves discolored [67]. Furthermore, some biochar's may pose a direct threat to soil biota, and their functions may explain some of the lower crop yields reported in the literature. These may be short-term effects that must be taken into account and evaluated for suitability as a soil amendment.

Future Perspective

The soil properties of biochar-amended filed soils with a long ageing time may differ significantly from those of laboratory-based short-term experiments, such as column and leaching studies. Nutrients released from 'fresh' biochar are attributed to short-term increases in crop growth. However, one study hypothesized that the long-term effects of biochar on soil nutrient availability are due to an increase in surface oxidation and CEC, which intensifies over time), and that this can result in greater nutrient retention in 'aged' biochar compared to 'fresh' biochar [68]. This mechanism must be demonstrated in the field over a long period of time. Long-term studies determining nutrient dynamics in biochar-amended soil, however, are still lacking. Further research should be focused on predicting nutrient dynamics in biochar-amended soil by developing and improving available kinetics models in both laboratory and field settings. Understanding the various mechanisms affecting soil nutrient availability and fertility over time is critical for studying nutrient dynamics. According to one study, biochar has a high pesticide sorption capacity and can accumulate pesticide residues in soil. The release of pesticides from biochar, which could act as a new source of pollution, has not been taken into account in most short-term studies. As a result, it is preferable to assess the long-term environmental fate of pesticides that have been sequestered. Currently, the use of biochar for pesticide-polluted soil remediation is primarily based on laboratory, greenhouse, or small-plot short-term experiments. Nonetheless, field conditions are complex, and biochar properties can change over time due to ageing, oxidation, or microbial degradation, affecting both pesticide adsorption and hydrolysis capacity. Future studies will therefore require large-scale and long-term field trials.

Conclusion

In order to increase sustainable agricultural productivity and conserve natural resources, integrated nutrient and pest management is required. Fertilizers and pesticides are important plant nutritional and protective agents for increasing crop production in agriculture development. However, fertilizer use efficiency in crop systems is typically very low. Furthermore, indiscriminate pesticide use can lead to severe environmental contamination. Biochar amendment in agricultural soil may be a suitable method for improving plant nutrient uptake and pesticide degradation. Biochar can be used to improve fertilizer utilization efficiency and soil fertility due to its large surface area, high number of functional groups, and good stability. Biochar can not only improve nutrient adsorption (e.g., $NO3^-$, $NH4^+$, and PO_4^{3-}) thereby reducing nutrient leaching, but it can also reduce gaseous N losses. Furthermore, the nutrients that have been adsorbed by biochar can be released into the soil later (slow-release fertilizer). Furthermore, biochar has the potential to accelerate pesticide degradation in soil and reduce pesticide uptake by plants. On the one hand, the addition of biochar to soil may improve pesticide removal rates by catalyzing the chemical hydrolysis process. Microbial activities, on the other hand, may be increased after the application of biochar to polluted soil. Notably, pesticide sorption on biochar can reduce the free pesticide concentration in soil solution, thereby impeding the hydrolytic process (chemical degradation) and lowering pesticide bioavailability (biodegradation). As a result, pesticide sorption in biochar-amended soil may be detrimental to degradation. The function of biochar in practical applications is determined by the feedstock, pyrolysis temperature, and application rate. Overall, biochar amendment can improve overall soil health and crop yield by increasing fertilizer use efficiency, soil fertility, and pesticide degradation, resulting in a benefit for sustainable agriculture.

Further research should concentrate on the following identified knowledge gaps: (1) long-term effects of biochar on soil properties and large-scale field trials should be considered; (2) biochar characteristics vary with different biomass materials and pyrolysis conditions, necessitating the production of biochar specifically designed for soil management based on soil properties and environmental conditions; (3) In order to maximize the efficiency of pesticide remediation, the dynamic mechanisms of pesticides between microorganisms and biochar should be understood; (4) more research is needed to thoroughly investigate the influencing factors for pesticide degradation by microorganisms and biochar; and (5) the synthesis and application of functionalized biochar as a potential material for soil amendment and remediation should be evaluated.

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Conflict of Interest

Author does not show any conflict of interest

Reference

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