Chapter

Sustainable Use of Biochar in Environmental Management

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Abstract

Conversion of agricultural wastes into eco-friendly and low cost biochar is not only a smart recycling strategy but a panacea to environmental pollution management. Agricultural wastes biochar can be an effective alternative technique for controlling contaminants due to its low cost, high-efficiency, simple to use, ecological sustainability and reliability in terms of public safety. Biochars have made substantial breakthroughs in reducing greenhouse gases emissions, reducing soil nutrient leaching, sequester atmospheric carbon into the soil, increasing agricultural productivity, and reducing bioavailability of environmental contaminants. Recent advances in the understanding of biochars warrant a proper scientific evaluation of the relationship between its properties and impact on soil properties, environmental pollutant remediation, plant growth, yield, and resistance to biotic and abiotic stresses. The main factors controlling biochar properties include the nature of feedstock, heat transfer rate, residence time and pyrolysis temperature. Biochar efficacy in pollutants management largely depends on its elemental composition, ion-exchange capacity, pore size distribution and surface area, which vary with the nature of feedstock, preparation conditions and procedures. The chapter explored the possibility of using biochar from agricultural wastes as a suitable alternative for the remediation of environmental pollutants, soil conditioning and the long-term biochar application in the environment.

Keywords: agricultural waste, biochar, elemental composition, carbon sequestration, environmental pollution

1. Introduction

Agricultural waste has been widely studied for at least 6 decades now [1]. This waste stream continues to increase in line with agricultural production [2]. This has negative impacts on the environment (soil, water and air) and human health [1]. Though agriculture accounts for 21% of global greenhouse emissions [1], it is its solid waste that is most obvious and an immediate environmental problem. Meanwhile, the world is fighting for zero solid waste [3]. Some uses of agriculture waste include; the fertilisation of farms through animal manure, the use of agriculture solid waste as adsorbents (ie, for heavy metal remediation), production of biochar from agricultural waste, use of agricultural waste as animal feed and as heating (energy) sources. Renewable energy (biofuels) can also be produced from agriculture waste [4]. The reduction in the quantity or total elimination of agricultural solid waste is an important consideration in the promotion of environmental health. One viable method to safely reduce agricultural solid waste is to convert them into biochar.

Biochar is a carbon-rich by-product produced from the thermochemical conversion of biomass feedstock under partial or total absence of oxygen (pyrolysis) [5]. Principally, biochar is produced through various thermochemical conversion methods such as low pyrolysis, fast pyrolysis, and gasification, under different process parameters [6]. Biochar production and application has increased significantly recently. Significant attention has been given to biochar in relation to agriculture, climate, energy and environment [7]. The adsorption capability of biochar can largely be accrued to its surface chemistry, specific area, and pore structure [8]. Humans over the years have used biochar for various activities due to its naturally occurring characteristics like surface functional groups, thermal recalcitrance, cation exchange capacity, calorific value, specific surface area, porosity, electrical conductivity, volatile contents, fixed carbon and pH [8]. These properties have been traversed for numerous beneficial application such as the amendment of soil [8]. Due to the continuous increase in food insecurity, greenhouse gases emissions and environmental safety demands, biochar in recent years have been linked to the development of sustainable agriculture and soil management as well as carbon sequestration [9].

Biochar application has proven to be a very favourable method for simultaneously solving the numerous multipronged issues. The bioavailability of toxic metals in water and soil can be reduced using biochar, hence, biochar aids in subsiding toxic metal pollution as well as enhancing the quality of contaminated water and soil [9]. Biochar is capable of removing inorganic and organic contaminants due to its intrinsic properties and characteristics such as high cation exchange capacity, non-carbonised fraction, coupled with high surface area and oxygen-rich functional groups on surface [10].

The emission of greenhouse gases poses a great challenge to the industrial world we have today [11]. This has greenhouse gas emissions have a significant adverse impact on the environment including air pollution and inducing climate change [12]. Industrialisation is required for human perpetuity and development hence pollutants generated through the processes cannot stopped, however, it can be reduced by replacing toxic substances and polluting compounds with less toxic substances that has both political and economic feasibilities [13]. There is the need to manage and protect soil, water and air sustainably during large scale agricultural practices and massive industrial activities. This can be done through the use of biochar which is carbonaceous product of biomass pyrolysis.

Biochar has been widely known for its ability to serve as remediator of contaminant, plays a vital role climate change mitigation and bioenergy production. Biochar could have an important effect on soil biological and nutritional properties as well as greenhouse emissions. It is evident that most of the Sustainable Development Goals (SDGs) can be achieved through biochar application and production. It has been proven that biochar could be a sustainable solution for numerous problems that is putting the earth at risk, hence, much research needs to be carried out on the production and application of biochar as one of the most important and beneficial steps to take.

1.1 Conversion of agricultural waste into biochar

Most agricultural solid waste can be converted into biochar [14, 15] and there are different methods for the production of biochar from this waste stream. These include hydrothermal carbonisation [16], gasification and pyrolysis [15]. However, pyrolysis is the most used method for the production of biochar [14]. This involves the irreversible thermal decomposition of organic substances at higher temperatures under anoxic conditions. Biochar from pyrolysis can be used as an energy source [17] and for soil quality improvements. With the production and use of biochar from agricultural waste, a circular economy within the agricultural industry can be realised. Besides biochar, pyrolysis also produces volatile liquids and could either be slow, fast, flash and intermediate pyrolysis [18]. Slow pyrolysis is usually carried out below the temperature of 450 °C [18], at atmospheric pressure [15] and takes several hours to complete. A heating rate of 17 °C min^{-1} may be used [19]. The main product of slow pyrolysis is char [18]. Traditional Kilns and special reactors (ie, Elsa barrel pyrolyser) are used for slow pyrolysis. The source of feedstock for biochar production can influence its quality in terms of environmental safety and sustainable use. Thus feedstocks (wastewater sludge, municipal and industrial solid wastes, etc) which are potential sources of pollutants (heavy metals, PAHs, PCBs, etc) should be avoided. Biochar from these feedstocks can therefore serve as secondary pollutants [20] and require further treatment before use.

1.2 Biochar elemental composition

The characteristics and application of a substance is determined by the composition and structure of that substance. According to literature the composition of biochar is made up of elements such as carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulphur (S), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), and silicon (Si). Carbon takes up more 60% of the biochar contents followed by H and O. The ash contains mainly the mineral elements [21]. The C found in biochar is aromatic carbon which are in irregular piles or stack of stable aromatic rings [22]. Different variants of carbon compounds most likely consists of alcohols, fatty acids, phenols, esters, humic acid and fulvic acid. Relatively, humic acid and fulvic acids are found in fresh biochar, livestock manure biochar and low temperature pyrolytic biochar [23]. Biochars within a C-N heterocyclic structure have nitrogen to be largely present on the surface and the available N is very low in biochar [9]. Phosphorus is relatively low in biochar. The availability of P greatly varies, and has a negative correlation with carbonisation temperature. This differences may be as a result of high pH value and phosphates containing Ca and Mg formed during carbonisation processes [24, 25]. The contents of K, Ca, Mg, and Na is largely dependent on the type of biochar. Low-valence metal ions such as K and Na are more available than the high-valence metal ions such as Al, Ca, and Mg in biochar. In general, the elemental composition and activity of biochar are related to raw materials, conditions of carbonisation process and pH [24].

Biochar's mineral component has been given less attention as compared to carbon. Current studies suggested that minerals biochar can significantly impact biochar attributes, hence affecting its use either directly or indirectly. According to literature Mg, Ca, K, and P in biochar can become a direct source of mineral nutrients thus promoting plant growth attributes and anions including CO_3^{2-}, OH^-, SO_4^{2-} and PO_4^{3-} leached from biochar are largely significant in eliminating toxic metals through the formation of metal precipitates [26]. Mineral components and carbon of biochar contribute significantly to the removal of toxic metals from solutions [26]. Biochar contain sulphur are much more efficient in making complex surfaces and could be useful in heavy metal removal from contaminated water. The porosity and surface area of biochars are important physical features which affects the adsorption of heavy metals capability from water. In terms of environmental application, molar ratios (i.e. O/C and H/C) are important factors that plays significant roles in determining interface interactions between the surface of the biochar and target matrices [27]. The meso-porous and macro structure of biochars derived from plants are known to be reliant on the intrinsic makeup of the feedstock, which is very vital for determining pollutant adsorptive and water-holding capacity in soil and solution systems [28]. A well-developed pore structure of biochars that consist of stable aliphatic chain structure, and high mineral content [29], have the potential to control water pollution, mitigate greenhouse gas emissions, and remediate soils [30]. The potential to utilise biochar for various applications is related to its properties.

Biochar with high porosity and plenty of liming and fertiliser-related elements (such as N, P and K) is preferred for improving soil properties [31]. A study conducted by [32] also indicated that the innate minerals of biomass could affect biochar properties significantly through interaction with its organic contents during pyrolysis process. However, removal of these intrinsic minerals before the pyrolysis process could significantly increase the optimum pyrolysis temperature (370 vs. 350 °C) required for the conversion of the biomass into biochar, as compared to untouched biomass. Interestingly, about 30.1% of C content of biomass could be secluded into biochar when there are no inherent biomass materials, simultaneously, lower amounts of low-molecular-weight organic compounds would be emitted during pyrolysis [32]. Therefore, the type and amount of minerals in biomass must be optimised according to the intended environmental application of biochar.

1.3 Role of biochar in pollution management

The continuous increase in the world population has cause an accompanying increase in anthropogenic polluting activities. This situation has caused several problems including global increments in atmospheric temperatures, droughts, floods, acid rains and increments in the spread of diseases. Effective and affordable solutions to these problems are yet to be arrived at. Biochar has been found to possess the potential to directly and indirectly alleviate the occurrences and effects of these problems. It uses are broad and includes the removal of pollutants (organic and inorganic) from wastewater [33]. Biochar have used been to remove antibiotics from wastewaters. Heavy metals (Cu, Pb, Ni, Cd) [34] and nutrients (nitrogen and phosphorus) [35] in wastewater have also been removed with biochar. Biochar can be used to either replace or augment sand filters in wastewater treatment because of its ability to remove particulate matter and pollutants such as pathogens [16]. It has also been used for chemical oxygen demand (COD) removal efficiency of 74 ± 18% was recorded in a treatment process [36].

The environment or surrounding systems are often degraded by contaminants discharged from residential, commercial and industrial sources. Literature reveals that soil and water media are more affected by both organic and inorganic contaminants in an ecosystem which is largely the cause of anthropogenic activities. Over the years, there is a rapid increase in technological advancement in soil and water remediation. One of the most paramount technologies is the reduction of bioavailable contaminants which would in turn lead to a significant decrease in the accumulation of toxic substance in plants and animals.

Materials that are carbonaceous have been adopted as sorbents for organic and inorganic contaminants in soil and water for a very long time now [37]. The multifunctional properties of biochar showed the potential as a sorbent for organic and inorganic contaminants in soil and water. The greatest concern of organic contaminants such as pesticides, herbicides, polycyclic aromatic hydrocarbons, dyes, and antibiotics have been a concern due to its toxicity and accumulative properties [38]. In the soil medium, biochar has been used for heavy metal sequestration [39, 40]. In this process, heavy metals are immobilised not removed and maybe converted into hydroxide, carbonate, and phosphate precipitates [40]. Sequestration of pesticides from polluted soils [15] and carbon sequestration (climate change mitigation measure) have also been achieved in soils amended with biochar [15]. In recent years biochar has become a focus for most researchers in the field of soil environment due its increasing potential to serve as carbon sinks, reducing greenhouse gas emissions, reducing the pressure on the burning of stray and finally remediating contaminated soil.

Properties of biochar such carbonaceous materials, degree of aromatization, elemental composition, pH, pore structure, surface chemistry, etc., plays vital roles in its ability to adsorb organic pollutants [41]. Biochar therefore reduces CO_2 emissions into the atmosphere [39]. The indiscriminate exploitation of natural resources and the rapid growth of environmental destruction resulting from anthropogenic activities have already posed a burden on efforts to sustain natural environment. Biochar's uses also includes the neutralisation of acidic soils and this is because of its calcium and magnesium carbonate contents [39] and ability to elevate pH [40]. Reducing acidity may however negatively affect acid loving worms and fungi in the soil environment [42]. Moreover, biochar can be used to enhance the biodegradation of organic pollutants because of the availability of suitable surfaces for microbial attachments [40] and the introduction of nutrients such as N, P and K [20]. In anaerobic digesters, biochar has been used to limit the effect of NH_4^+ [43] and may as well be used as buffering agents in these digesters [44].

Biochar has also been found to have many uses in air quality improvements. It has been used to control the release of air pollutants like NO_2 and NO which respectively presents greenhouse effects and localised ozone formations [45]. For instance, biochar has been used to achieve a 67% NO removal from soils [46]. This is achieved through biochar's ability to reduce the bioavailability of nitrogen to soil microorganisms for their metabolic activities [47]. The removal of gaseous mercury has also been achieved using biochar [48]. Several research reports show that, biochar surfaces are usually negatively charge thus have high affinity for positively charged metal ions [48] including $Hg^{2+.}$ Removal efficiency usually depend on biochar properties (surface and elemental properties), feedstock and pyrolysis conditions under which biochar was prepared [48]. Though biochar can be used to reduce CO_2 emissions, it has low affinity for CO_2 and thus requires modifications for effective CO_2 capture [48]. One modification method is impregnating biochar with nitrogen and this improves biochar removal of CO_2 of up to 55% [49]. For H_2S gas, biochar has been used to achieve as high as 95% removal efficiency from a biogas production process [50]. It was shown that H_2S removal is better in the presence of hydroxide and carboxylic functional groups [51]. Other gases that have been removed with biochar include; ammonia and toluene [52], ozone [53], benzene [54], methyl tert- butyl ether and [55]. Though agriculture wastes are abundant for the production of biochar, it is however necessary to practice the sustainable utilisation of biochar (**Figure 1**). This is particularly necessary because biochar production consume energy and may release pollutants (gaseous and particulate matter). Sustainable utilisation of biochar includes the reuse of biochar, production biochar from feedstock which are less likely to contain pollutants and the use of calculated/optimised quantities in field applications.

It is having been demonstrated in numerous studies, the excellent performance of biochar in the removal of organic contaminants as well as inorganic contaminants. Generally, the adsorption of inorganic contaminants by biochar depends on biochar surface properties, contaminant type and pH. Phosphate adsorption in biochar is decreased by high aqueous pH values. The effect of P on the remediation of Cd by biochar was studied by [56]. The adsorbed P remains bioavailable, allowing the formulation of slow release of P fertilisers. Leaching of P in agricultural soil could be minimised by 89.25% by introducing biochars imbued with Mg whilst the

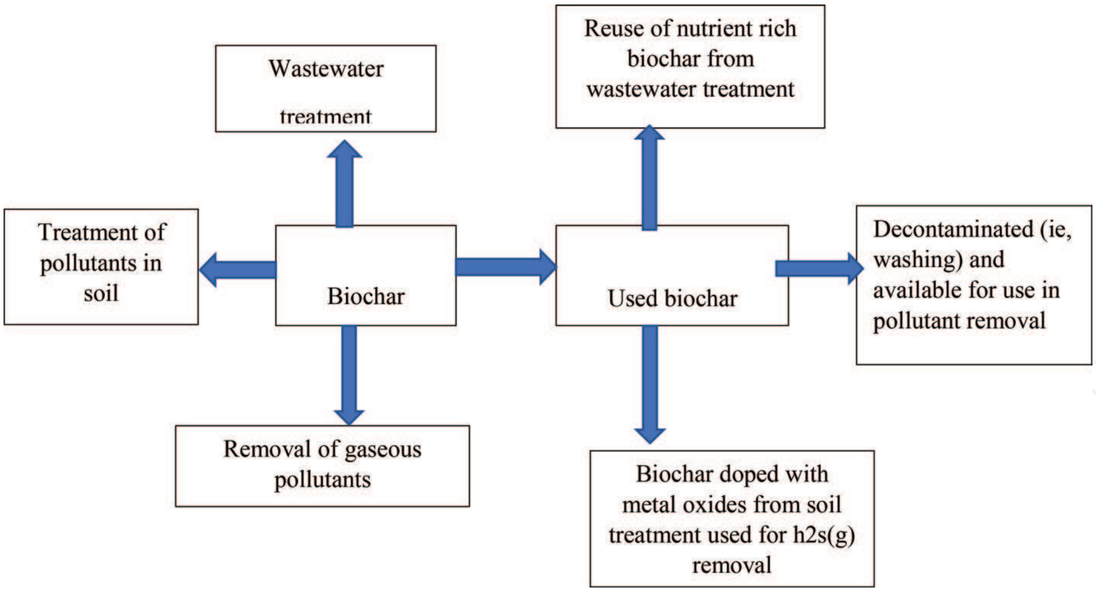

Figure 1.
An illustration showing a pathway for the sustainable utilisation of biochar.

availability of P of the surface at the same time is increased by 3.5 folds as compared to the soil without biochar [57].

Recent studies have been demonstrated the use of biochar for water treatment and purification have gained a lot of attention. [58] indicated that micro-nano-engineered nitrogenous cow bone biochar (pyrolysed at 600 °C) was created which was able to adsorb 165.7, 287.6 and 558.9 mg/g of Cd(II), Cu(II), and Pb from water, respectively. Also a different study demonstrated the adsorption of ammonium from water using ball mining bamboo biochar where the adsorption was even more than three folds as compared to pristine biochar (7.0 vs. 22.9 mg/g) [59]. Toxic metals in soil medium can be remediated just like how toxic metal remediation in water medium is being remediated using biochar. For instance, calcium-based magnetic biochar minimised the bioavailability of Cd and As in soil through the transformation of thew metals into fractions that are stable [60]. The pH and cation exchange capacity of the soil increases due to the addition of porous biochar which lead to Cd remediation. The remediation of Pb and Cd polluted soil was also performed using thoil-modified biochar and the maximum adsorption capacities recorded were 61.4 mg/g and 45.1 mg/g, respectively [61]. Addition of biochar into soil may indirectly remediate toxic metals via the enrichment of microorganisms that are capable of remediating toxic metals [62].

Besides the removal of inorganic contaminant by biochar, it has the potential to remove hazardous organic compounds such as dyes, antibiotics, pesticides, oils, phenolics, polynuclear aromatics and persistent organic pollutants. The type of contaminant and biochar surface properties dictates how organic compounds are adsorbed. The mechanism for adsorbing organic compounds can be classified as pore-filling, p–p interaction, electrostatic attraction, cation exchange, hydrophobic interactions, complexes adsorption, and partition uncarbonised fraction [63]. Biochars engineered have been greatly used to remove organic contaminants. A typical example is the improvement of levofloxacin removal by cerium trichloride-treated biochar [64]. The treatment of cerium could be correlated with increasing the O-containing functional groups on the surface of biochar. Also, the structure of CeO_2 mesoporous, hence, its adsorption capacity as biochar can be improved [64]. In order to improve the surface area and the sizes of each pores, the surface polarity was also increased due to higher presence of O-functional groups [65]. The availability of these functional groups enhances the sorption organic contaminants via the bind of H_2 and complexation between biochar and organic compounds [66].

Biochars that are engineered are also good at adsorbing biological contaminants from water. For instance, developing wood biochar through H_2SO_4 oxidation and the resulting increase in surface area of the biochar and also resulting in an improved retention of *Escherichia coli* from stormwater [67]. Recently, the characteristics as well as the properties of pristine biochar developed from pyrolysed banana pseudostem biomass at 600 °C was improved significantly by Fe_3O_4 coating [68]. This engineered biochar demonstrated superparamagnetic properties and a significantly high surface area and was used for removal of the antibiotic furazolidone from wastewater efficiently. Adsorption of antibiotics from wastewaters/ agricultural drainage is crucial in order to halt the prevalence of drug-resistant pathogens [69] and to avoid new threats to human and animal health [70]. Also, the breakdown or depletion of these compounds does not actually make them less lethal or harmless. For example, degradation of furazolidone biologically may lead to the formation and development of carcinogenic metabolites [71]. This further depicts the relevance of biochar application in removing them via the adsorption mechanism.

Biochar engineering increases its efficiency in pesticides removal. In a successful field experiment, steam activated (800 °C for 45 min) almond shell biochar that was slowly pyrolyzed at 650 °C for 1 h under N_2 was used for the removal of dibromo chloropropane from well waters [72]. Biochar can also be used for the adsorption of solvents from water. Trichloroethylene, for example, has been eliminated from water using biochars developed from soybean stover [73]. The pyrolysis temperature is the major determinant of biochar adsorption capacity. Specifically, the highest adsorption capacity for trichloroethylene (32.02 mg/g) by the biochar was produced at the highest temperature (700 °C) depicted [73]. Biochar can be employed in water purification processes via the development of hybrid techniques such as permeable reactive barriers, biochar-augmented biofilters and biochar-based membrane filtration [74]. In general, the removal capacity of biochars can be greatly enhance or improved through bioengineering can be achieved via hybridisation techniques.

1.4 Role of biochar in environmental safety and sustainable agriculture

Agricultural lands are now degrading due to continuous farming leading to nutrient mining and decreased soil organic matter levels. Reduced levels of soil fertility in agricultural fields are nowadays becoming the prime concern for cultivating crops. The waning of soil on agricultural fields remains until improved management practices improve them. Soil health is the basis of the vital and supportable food system. Nutrient cycling and release and nutrient uptake are usually disturbed as the agricultural land is continuously cultivated, which affects the natural supplies of vital nutrients for plant development to decline and inhibits the growth rate of crops of farm soils. Biochar improves soil health, improves soil fertility, improves crop yields, and sequester carbon depending on the application rates, type of feedstocks, and temperature.

The incorporation of biochar into the soil improves plant health and crop productivity which been linked to four main mechanisms. The first mechanism is in connection with the capability of the biochar to stimulate beneficial microbes in the rhizosphere [75]. As a source of reduced carbon compounds and by increasing the availability of micronutrients, biochar provide beneficial sites to microbial populations [76] and other plant-growth-promoting microbes [77]. However, increase in microbial biomass resulting from microbial growth following biochar application has been reported to be as a result of the; effect of nutrient and water retention, creation of active surfaces that provided optimal habitat for microorganisms, weak alkalinity and partial inhibition of destructive and simultaneous support for beneficial microorganisms [78].

Secondly, the high water retention capacity of biochar leads to enhancement of water regime of the soil, and this is of special advantage to sandy soil area where the biochar will lessen the leaching away of moisture, thereby reducing water loss, whilst it reduces the risk of water-logging in clay soil by promoting water drainage [79]. The third mechanism is related to the capability of biochar to adsorb and neutralise phytotoxic organic molecules such as anthropogenic, xenobiotics and natural allelopathic compounds. This detoxifying ability is directly associated with the increases of specific surface area that occur during pyrolysis [10]. Increase in soil pH is the fourth mechanism, which is significantly beneficial to acidic soils [80].

1.4.1 Biochar effect on soil properties

Applying biochar to infertile soil reduces the bulk density and enhances the soil's total pore volume and water holding capacity to retain and mobilise nutrients to the soil-root system [81]. Primarily, biochar has a marginal effect on compaction. Still, on a long-term scale, with the ageing of biochar, modification is projected [82]. The application of biochar significantly influences several chemical properties such as pH, electrical conductivity (EC), cation exchange capacity (CEC), organic carbon, availability of nutrients. The use of biochar in the soil decreases soil acidity by enhancing soil pH as it is alkaline [9]. It also helps increase CEC, organic C, and exchangeable cations (such as Ca, K, Mg) [83]. By enhancing soil pH and CEC, it increases the availability of nutrients to plants. Soil fertility is improved by biochar treatment, primarily through two mechanisms: nutrients (like K, P, many micronutrients) and the soil or nutrient retention from other sources, including nutrients from the soil itself. Biochar shows a net positive effect on crop growth by increasing nutrient elements' availability (C, N, P, Ca and Mg) as it absorbs and slowly releases fertilisers [84]. Higher CEC of biochar treated soil binds cations to retain nutrients on biochar surface, humus, and clay rather than leached, making them further accessible for plants' uptake. Naturally, aged biochar generally shows a higher negative charge that promotes more soil aggregation and nutrient availability than fresh biochar or artificially old biochar [82]. The rise in plant-available water by biochar proposes that biochar could reduce irrigation frequency in croplands, mainly in low water areas. Biochar's positive effect on upsurging water holding capacity can be more extensive in sandy soils with lower micro-porosity and a smaller specific surface area than clayey soil.

Various life forms, including fungi, bacteria, nematodes, protozoa, earthworms, arthropods, indicate good healthy soil. Biochar addition has different influences on abundance, activity, and soil biological communities' multiplicity than fresh organic matter [76]. Research shows that biochar treatment results in higher microbial respiration by enhancing soil biodiversity and creating pores for soil microbes due to the complex aromatic structure, absence of carbon in biochar, and higher biochar stability than other fresh organic matters. Biochar can act as a habitat for microorganisms as it has a highly porous nature, and it can alter enzyme activity on or around biochar particles. Besides, by providing a more favourable habitat to microorganisms, it can modify soil's physical and chemical environment [76]. Moreover, microbial biomass and composition can also be affected by biochar addition. The pores of biochar can physically protect soil microorganisms. The buffering capacity of biochar that can resist changes in pH helps maintain favourable pH and abate pH instabilities in biochar particles supporting increasing microbial growth in micro-habitats [85].

The addition of biochar to soil sequester carbon and retain nutrients, thus promoting soil health and fertility and agronomic benefits. Moreover, nutrient availability also varies with the physico-chemical properties of biochar and the type of feedstock materials. Generally, biochar produced from feedstocks like manures and animal products is considered rich in nutrients related to those made from plant materials, mostly from hardwoods [86]. Biochar and other aromatic black carbons persist in soil for a more extended period and retain cations than any other organic carbon form. The ageing of biochar retains more cations than fresh biochar. Continuous fertilisers in the soil cause nutrient leaching from the soil that can deplete soil fertility, increase soil acidity, reduce crop yield and most notably deprive soil and environmental health. Higher absorption of cations and anions (like phosphate) due to biochar to soil restrict excess nutrients' leaching. Besides, biochar decreases the leaching of nutrients like N, P, Mg, Ca, nitrate and ammonium from soil [87].

1.4.2 Interaction of biochar with soil, plant and microorganisms

Biochar provides sites that can hold nutrients and other organic compounds as it exhibits natural oxidation through the formation of functional groups [82]. Biochar particles are highly associated with clay and silt-sized minerals, and oxidised biochar particles may be bound to soil minerals, in so doing decreasing the potential of its decomposition [88]. This association enhances the ability of soil-biochar-complex to adsorb organic compounds available in the soil whereas the biochar also interrelate directly with organic matter of soil by sorption [89]. Largely, amending soils with biochar helps to restore the health of the soils by increasing organic matter content and water holding capacity, balancing its pH, and re-establishing microbial populations. It also results in easing compaction, allowing the establishment of vegetation, recreation of ecological function of soils, decreasing bioavailability of toxic pollutants, leachability and mobility of contaminants, as well as improve soil drainage compared to the traditional remediation techniques [90]. The positively charged particles in biochar after pyrolysis are usually transmuted into oxides, hydroxides, and carbonates (ash) which behave as liming agents when incorporated into soil. Biochar is composed of low density material that The incorporation of biochar enhances reduction in soil bulk density as result of the composed low density material, thereby increasing root penetration, water infiltration, soil aeration and aggregate stability [87].

1.4.3 Impact of biochar application on nitrogen fixation and plant productivity

Amending soils with biochar enhances biological nitrogen fixation. The nitrogen available in the biochar is usually higher than that of the soil due to the high carbon/nitrogen (C/N) ratio of the biochar, and the resulting N immobilisation [76]. The incorporation of biochar in the soil results in the combination of factors related to soil nutrient availability and simulation of plant microbe interaction, along with increases in nitrogen/nutrient levels. [91] reported an enhanced biological N-fixation in leguminous crops in soils amended with biochar. The increase in the availability of major plant nutrients due to biochar application is as a result of the release of some small amounts of nutrients that would be available to soil biota [92].

Biochar promotes plant productivity and yield through a number of mechanisms. It changes the physical conditions of plants. The dark colour of biochar alters the thermal dynamics and facilitates rapid germination of plants, allowing more time for growth compared with soils that are not amended with biochar [93]. Amendment of soils with biochar must be done based on extensive field testing since there are no specific recommended application rates. [94] opined that incorporation of 5–50 tonnes of biochar per hectare, with proper nutrient management gave positive effects on crop yields. Poultry litter biochar has been reported to improve the yield of corn, cowpea and radishes by 140, 100 and 96% respectively [94]. Field incorporation of biochar below 30 tonnes/ha has been reported to increase crop productivity for legume crops (30%), vegetables (29%) and grasses (14%) compared to corn (8%), wheat (11%) and rice (7%) [95]. Additionally, incorporation of biochar produced from wastewater sludge resulted in 64% increased production of cherry tomatoes above the control soil conditions at the rate of 10 tons/ha [96]. According to [97] sawdust and rice husk biochar significantly improved uptake of N, P and K by maize plants, and also significantly enhanced plant height, number of leaves, fresh and dry weight of cobs of maize.

1.4.4 Role of biochar in sustainable plant disease management

The ever increasing desire to increase agricultural efficiency in terms of producing maximum crop yields and produce is only achievable if pest and disease agents affecting crop productions are effectively monitored. Interventions such as cultural, biological, chemical and regulatory measures are the main approaches to plant disease management. The chemical method, since its adoption over a century ago, had assumed a position of significance and preferred over the existing cultural method as a result of its effectiveness in the management of diseases and pests. The availability, stability and quick-action, relatively low cost of the chemicals and ease with which they can be used, limits the harm done to crops. With the apprehension of the havoc, however, caused by continuous and persistent use of chemicals either by misuse or abuse, with the consequent degradation of ecological community of most of the farm sites based on their effects on both the target and non-target organisms, has led to the destruction of beneficial organisms and the natural predator in the eco-system. The normal functioning of the ecosystem is obstructed if the organisms develop resistance to the chemicals used, thus resulting in pests evolution. Consequently, agricultural workers suffer occupational exposure to pesticides whilst the general population is exposed to pesticides pollution principally through the food chain and drinking water contaminated with pesticide residues which are carcinogenic [98].

1.5 The role of biochar in mitigating climate change

Biochar can satisfy the following targets: achieving food security by enhancing crop productivity, promoting soil health and quality by improving soil properties, avoiding land degradation, reduction of greenhouse gas emissions minimises climate change, and adsorbing hazardous elements onto its surface. The conversion of *terra preta* soil into highly fertile soil due to biochar application is excellent evidence of biochar's role in soil sustainability and the environment. Many greenhouse gases are from the agricultural sector primarily due to many crop residues burning. A considerable amount of CO_2 is released from the fields, hampering the quality of the environment. The use of biochar has been well-thought-out, a novel technique to make a slow continuing elimination of CO_2 from the terrestrial atmosphere due to its complex aromatic structure and recalcitrant nature. The conversion of residue into biochar is considered a better alternative against burning. About 50% C retains in the soil in converting biomass C to biochar C than traditional conservation agriculture and microbial degradation, providing a more stable soil C sink than burning or direct biomass application [9]. Thus, applying biochar to soils can play an essential role in C sequestration to mitigate climate change as its residence time is up to millennial time scales [99]. On a global ranking of removing C from the atmosphere, biochar-bioenergy can play a significant role in inhibiting erratic climate change. It helps to capture and store C from the atmosphere at lower prices, where biochar addition significantly enhances the crop yield. About 62–66% of CO_2 emissions could sequester within biochar [100]. Thus, biochar can be an advantageous element to sequester more CO_2 from the soil's atmosphere to mitigate climate change. Besides CO_2, the emission of other greenhouse gases such as methane (CH_4), nitrous oxide (N_2O) has become a significant threat to the environment. Biochar application to the soil decreases the emission of CH_4 by suppressing the oxidation of ambient CH_4 depending upon soil type, the properties of biochar, and environmental conditions. On the other hand, the impact of biochar on the nitrogen transformation process is still unknown. Compared with other fresh organic materials, biochar application helps reduce N_2O emission and NH_4^+ leaching from the soil. Biochar reduces N_2O emission at reduced paddy fields due to the oxidative reactions on the biochar surfaces with ageing [86]. The biochar addition at the rate 20 and 40 Mg ha^{-1} reduced the total release of N_2O by 10.7% to 41.8%, respectively [101]. Furthermore, soil N_2O fluxes have also decreased to 79% in biochar treated soil [102].

1.6 How safe is the use of biochar on the environment?

The process of biochar production transforms the easily oxidised carbon fractions present in organic residues into more stable forms [5] that can persist in soils for years [103]. The incorporation of biochar reduces the emissions of greenhouses gases [104] and can be considered as a climate change mitigation strategy [105]. On the other side of the coin, required quantities of this conditioner to improve soil productivity might be less comparable with compost or other organic amendments on the long run. Consequently, biochar also known as "the black diamond" is offered as a promising soil amendment of high economic and environmental value [106]. However, several environmental traits should be taken into consideration whilst using this amendment. The primary one to consider is the production process. During the pyrolysis process of biochar, significant emissions of CO_2 occur and this probably may raise the levels of greenhouse gases in atmosphere [107]. The second important issue has to do with the degradation of biochar in the soil. Under warm climatic conditions, biochar degradation is reported to be relatively high [6] and therefore, further emissions of greenhouse gases might take place from biochar-amended soils. The third relates to ethylene production, which is a by-product of the pyrolysis process of biochar [108]. Ethylene is increased considerably in biochar-amended soils to subdue several soil microbial processes [82]. Soil biota not only affects the physical and chemical properties of soil but also improves plant health [80]. Several researches have established the positive influences of amending soils with biochar on increasing crop productivity. Soils Amended with biochar have been proven to significantly improve macro- and micro-nutrients availability [6], even though many biochar additives have an alkaline nature [76]. Furthermore, amending soils with biochar reduces nitrate (NO_3) loss through leaching as well as the gaseous loss through release of nitrous oxide [92], which can positively boost plant growth [93].

However, the effects of amending soils with biochar are not always the similar and depend mainly on the features of the biochar used such as grain size and pyrolysis temperature. Fine biochar decreases soil hydraulic conductivity (EC), whilst the coarse biochar (particles were coarser than sand) did not affect the hydraulic conductivity of soils [95]. In addition, the pyrolysis temperature for the production of the biochar has a significant effect on ash content, pH, EC, and basic functional groups as well as carbon stability, which increases in biochar with increasing pyrolysis temperature [109]. Another positive influence of biochar as a soil conditioner is related to its ability to mitigate salinisation of arable lands [110]. It is noted that biochar plays positive significant influence on regulating the contaminants present in water and soils [111]. Conversely, many contaminants such as atrazine and acetochlor that are sorbed on biochar [107] may also originate from biochar [112] and this may reduce its efficacy [98]. Although biochar plays important positive roles on environmental sustainability, there is a stream of knowledge regarding the recommended application rates to soils to evade its negative potential effects on the environment.

2. Conclusion

The chapter explored the possibility of using biochar from agricultural wastes as a suitable alternative for the remediation of environmental pollutants, soil conditioning and the long-term biochar application in the environment. Agricultural wastes biochar can ensure environmental safety and sustainability. Minerals biochar can significantly impact biochar attributes therefore, the type and amount of minerals in biomass must be optimised for the intended environmental application. Biochars have made substantial breakthroughs in reducing greenhouse gases emissions, reducing soil nutrient leaching, sequester atmospheric carbon into the soil, increasing agricultural productivity, and reducing bioavailability of environmental contaminants. Biochar has been widely known for its ability to serve as remediator of contaminant, plays a vital role climate change mitigation and bioenergy production. The incorporation of biochar into the soil improves plant health and crop productivity.

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Conflict of interest

The authors declare no conflict of interest.

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