Chapter

Biochar: A Sustainable Approach for Improving Soil Health and Environment

Shreya Das, Samanyita Mohanty, Gayatri Sahu, Mausami Rana and Kiran Pilli

Abstract

Current agriculture faces multiple challenges due to boom in food demand and environmental concerns. Biochar is increasingly being recognized by scientists and policy makers for its potential role in carbon sequestration, reducing greenhouse gas emissions, renewable energy, waste mitigation and as a soil amendment. The purpose of this review is to provide a balanced perspective on the agronomic and environmental impacts of biochar amendment to soil. Application of biochar to soil can play a significant role in the alteration of nutrients dynamics, soil contaminants as well as microbial functions. Therefore, strategic biochar application to soil may provide agronomic, environmental and economic benefits. Recent findings also supported that in order to enhance crop yield, improve soil quality and soil health, biochar has proven significant role as fertilizer and soil conditioner respectively.

Keywords: biochar, carbon sequestration, soil conditioner, waste mitigation, crop yield

1. Introduction

Agriculture plays an important role in shaping the global economy. Now-a-days, food security is a major issue. Despite remarkable refinement of agricultural practices after World War II, the global food supply is yet incapable to fulfill the actual demands. Further, emerging issues of soil pollution, climate change and-Desertification still remains to be iron out for the agriculture sector [1]. The global food demand is anticipated to increase by 70% till 2050 with the burgeoning population [2] and meeting up this demand without compromising soil health and agroecosystem has turned into a big challenge in the agriculture sector. To meet the pressing demand for food; indiscriminate use of fertilizers, plant growth regulators, pesticides etc. has become a general practice. Their excessive use is a serious concern because of their adverse impact on the environment and the entire food chain.

Depletion in soil organic matter and soil nutrients, decline in agricultural productivity due to excess use of chemical fertilizers and changes in climate due to anthropogenic activities are posing great threats to the sustainability of agricultural production in the tropical regions. So it is becoming important to use organic fertilizer along with inorganic fertilizer for improving sustainability and maintaining soil health. Along with organic manures and composts, the use of biochar is quite a novel approach having potential benefits to both environment and agriculture as the former is a source of calcitrant carbon and the later contains recalcitrant form of carbon. Application of biochar to soil as a technique to improve the quality of soil has emerged in recent years. A common characteristic of biochar is that it comprises mainly stable aromatic organic carbon that cannot readily be returned to the atmosphere [3, 4]. The decomposition rate of biochar is 0.03% per year. Once it is applied, it is able to help in water and nutrient retention for next 5–8 years. Furthermore, biochar can reduce the risk of environmental pollutants (organic and inorganic) from soils by forming complexes or through sorption of organic compounds like herbicides [5].

2. Production of biochar

2.1 Feedstocks/raw materials

Various organic materials are suitable as feedstock for the production of biochar. Biochar can be produced with raw materials such as grass, cow manure, wood chips, rice husk, wheat straw, cassava rhizome, and other agricultural crop residues [6]. Agricultural wastes (bark, straw, husks, seeds, peels, bagasse, sawdust, nutshells, wood shavings, animal beds, corn cobs and corn stalks, etc.), industrial wastes (bagasse, distillers' grain, etc.), agroforestry (*Gliricidia* twig, *Eucalyptu*s bark, *Pongamia* shell, *Eucalyptus* twig and *Leucaena* twig) and urban/municipal wastes [7, 8] have been extensively used, thus also achieving waste management through its production and utility. Hard wood biomass containing 10% moisture content is best for biochar production. After collecting hard woods, removal of barks can help to avoid lignin effects. Cellulose, hemicellulose, and lignin polymers are the principal components of biomass used for the biochar production.. Among these, cellulose has been found to be the prime component of most plant-derived biomasses, but lignin is also important in woody biomass.

2.2 Production process

Thermochemical conversion technologies are more popular than biochemical conversion technologies in case of biochar production as the rate of hydrogen production and yield are quite lower in the later. The former can further be divided into combustion, pyrolysis and gasification. Different thermochemical processes involved in biochar production are shown in **Figure 1**. Biochar which is obtained by slow pyrolysis from biomass waste (agricultural, municipal, animal, or industrial sources), is highly porous, fine-grained, carbon dominant product rich in paramagnetic centres having both organic and inorganic nature, with large surface area possessing oxygen functional groups and aromatic surfaces [9] with the primary goal of soil improvement. The pyrolysis temperatures generally employed ranges from 300 to 1000°C. Different types of pyrolysis along with their operating conditions are summarized in **Table 1**. In the absence of oxygen, Pyrolysis rapidly heats biomass, driving off carbon monoxide and hydrogen and turning the residue into biochar, a carbon rich solid. In this process, a mixture of volatile gases is released which can be captured and condensed into an energy-dense liquid called bio-oil. Further it can be refined into diesel and other hydrocarbon products. Recently, it has been reported that biochar obtained from the carbonization of organic wastes can be a substitute that not only influences the sequestration of soil carbon but also modifies its physicochemical and biological properties [15].

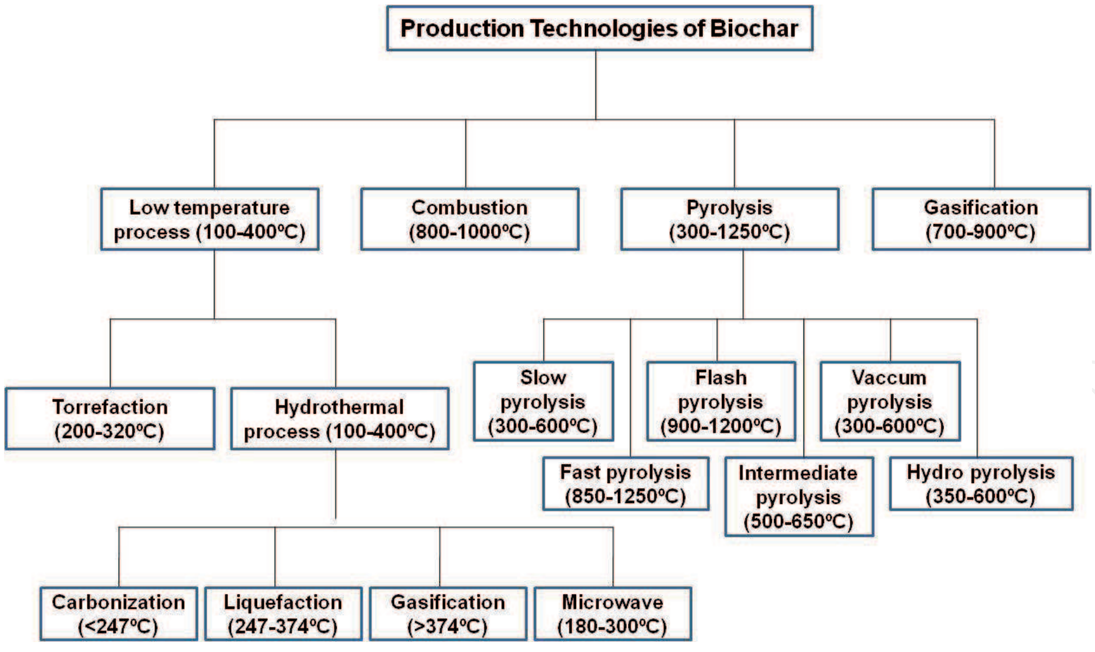

Figure 1.
Different thermochemical processes for biochar production.

Type of pyrolysis	Temp. (°C)	Heating rate (°C/s)	Pressure (MPa)	Residence time (s)	Particle size (mm)	Biochar yield (%)	References
Slow pyrolysis	300–600	0.1–1	0.1	300–550	5–50	20–40	Li et al. [10]
Fast pyrolysis	850–1250	10–200	0.1	0.5–10	<1	10–15	Li et al. [10]
Flash pyrolysis	900–1200	>1000	0.1	<1	<0.5	10–15	Li et al. [10]
Intermediate pyrolysis	500–650	1–10	0.1	10–20	1–5	15–25	Zhang et al. [11, 12]
Vaccum pyrolysis	300–600	0.1–1	0.01–0.02	0.001–1	—	25–35	Britt et al. [13]
Hydro pyrolysis	350–600	10–300	5–20	>15	—	—	Liu et al. [14]

Table 1.
Types of pyrolysis and their operating conditions for biochar production.

2.3 Factors associated with biochar quality

Specifically, the quality of biochar depends on several factors, such as the type of soil, metal, and the raw material used for carbonization, the pyrolysis conditions, and the amount of biochar applied to the soil (**Figure 2**).

The tendency of the surface functional groups to attract positive charges enhances the cation exchange capacity, which is an important property of biochar for remediation of metal-contaminated soils. The advantages of biochar with various physiochemical properties are shown in **Figure 3** [16].

The physical properties of biochar play significant role to its function as a tool for managing the environment. Research has been shown that biochar, when used as a soil amendment, improves soil quality and boosts soil fertility by increasing the

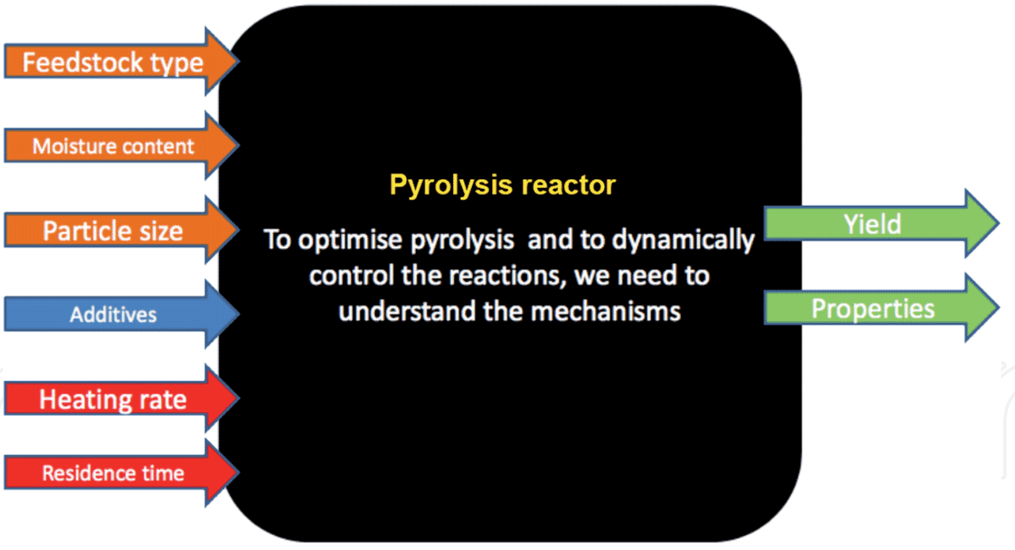

Figure 2.
Schematic diagram of factors affecting the quality of biochar.

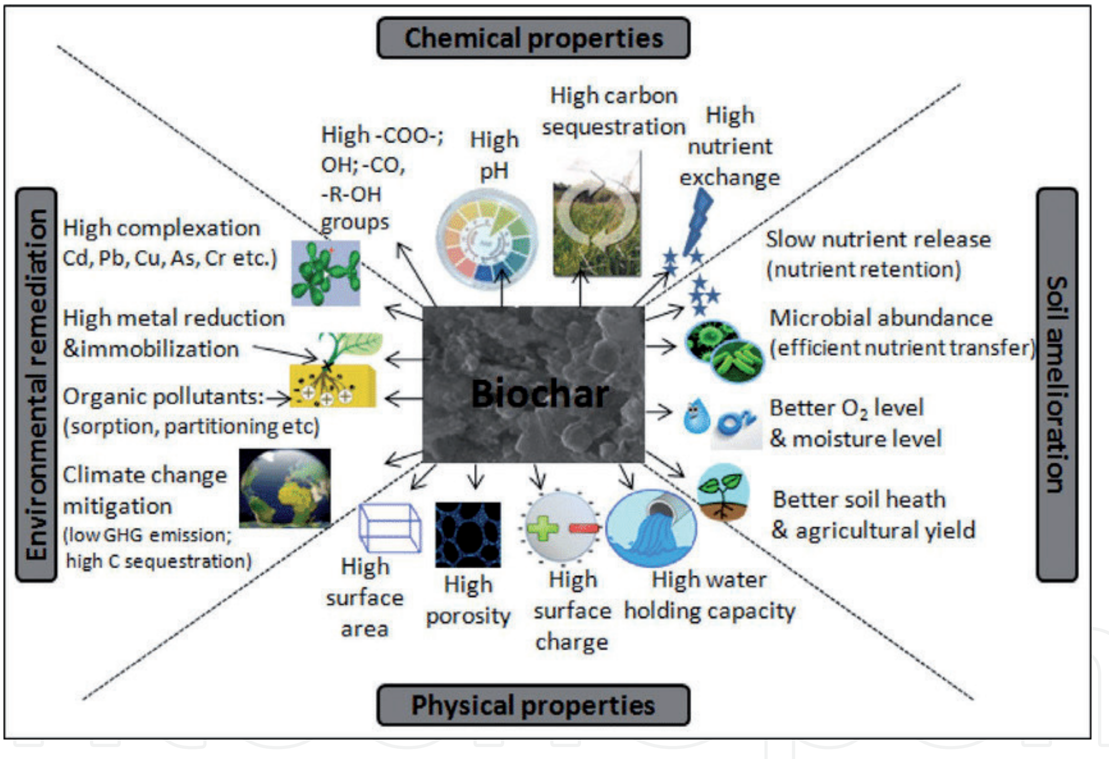

Figure 3.
Physicochemical properties of biochar.

moisture retaining capacity, soil pH, cation exchange capacity, attracting more beneficial fungi and other microbes, and preserving the nutrients in the soil. Biochar increases soil aeration and cation-exchange capacity, reduces soil hardening and soil density and changes the soil structure and consistency by changing the physical and chemical properties. In drought prone areas, the effects of drought on crop productivity can be reduced by addition of biochar due to its moisture-retention capacity. It has also been reported that it eliminates soil constraints that limit the growth of plants, and neutralizes acidic soil because of its basic nature [17].

As far as its chemical properties are concerned, biochar reduces soil acidity by increasing the pH (also called the liming effect) and helps the soil to retain nutrients and fertilizers. The application of biochar improves soil fertility through two mechanisms: adding nutrients to the soil (such as K, to a limited extent P, and many micronutrients) or retaining nutrients from other sources, including nutrients from the soil itself. However, the main advantage is to retain nutrients from other sources.

3. Effect of biochar on agricultural productivity, soil health and environment

Food security, climate change, declining soil fertility and profitability are the burning issues under the present scenario. Soil carbon is important for food security, ecosystem functioning and environmental health, especially in light of global climate change. Owing to its biological origin and physico-chemical properties, biochar (pyrolyzed crop residue) has the potential of carbon sequestration. Its higher stability against decay and capability to retain nutrients ensure the nutrient availability according to the crops need for a longer period.

3.1 Agricultural implications of biochar

Biochar has a diversed application ranging from use in agriculture and animal husbandry, flue gas cleaning, heat and power production, metallurgical applications, building material, to medical use. It has gained increasing popularity in the last years as a replacement for fossil carbon carriers in several of these applications in an attempt to reduce greenhouse gas emissions.

3.1.1 Biochar as a soil amendment

The burning issues as food security, climate change, declining soil fertility and profitability act as incentives behind the introduction of latest technologies of new farming systems. To reduce the risk of pollutant transfer to waters or receptor organisms in proximity, the amendment of soils for their remediation has proven a significant role.. In this context, the organic material such as biochar may serve as a popular choice owing to its biological source and direct application to soils with little pre-treatment. The two things which make biochar amendment superior to other organic materials are high stability against decay so that it can last for longer times in soil providing long-term benefits and high capability to retain the nutrients. Biochar amendment also play a significant role in improving soil quality by increasing moisture-holding capacity, soil pH, cation-exchange capacity and microbial flora [18]. The addition of biochar to the soil has shown the increase in availability of basic cations as well as in concentrations of phosphorus and total nitrogen [19, 20]. Another valuable property of biochar is suppression of emissions of greenhouse gases in soil. Due to the presence of calcium compounds, as well as improved physico-chemical and biological properties of soil, application of biochars and biochar amended composts is advocated to control the diseases caused by fungi and bacteria in soil. Bio-char can also adsorb pesticides, nutrients, and minerals in the soil, preventing the movement of these chemicals into surface water or groundwater and the subsequent degradation of these waters from agricultural activity.

3.1.2 Biochar as soil conditioner

From the agricultural point of view, the application of carbonization products for soil amelioration seems to be beneficial because the treatment improves the conditions for plant growth, leading to a better yield [21]. Furthermore, due to the rapid effects and relatively low costs of such treatment, biochars are more and more frequently used in processes of soil remediation and conservation. Moreover, the application of biochars to soil leads to increased contents not only of carbon but also of other biogenic compounds, such as phosphorus, potassium, magnesium and nitrogen [7, 22]. By increasing NH_3 and NH_4^+ retention, reducing N_2O emissions and eluting NO_3 ions, as well as inducing the development of nitrogen bacteria which directly affects the increase in soil productivity, biochar helps to store nitrogen. Biochar also impacts the physical properties of soil by improving its water retention, capacity to form aggregates, and resistance to erosion. Owing to their highly porous structure, carbonization products may create favorable conditions for microorganisms, as a consequence improving the fertility and productivity of soils.

3.1.3 Improving soil for crop production

Biochar is considered to be highly effective in the restoration of the fertility of soils. Many researches confirmed that the use of biochar leads to the improvement of the soil productivity [23]. The extraordinary properties and benefits of the use of biochar are not only limited to only to the area which was disturbed for obtaining biomass to generate bio energy but it has the ability to remain persistent in the soils for almost two to three years [19]. This shows that if the biochar is applied to the lands which are not used for bio energy production, it will increase the fertility of soil and will help in reducing the pollution of soil of that land from the inorganic chemicals.

3.1.4 Nutrient availability in soils

Biochar application leads to the increase in pH of the soil and that leads to improved availability of phosphorous and potassium [9] When biochar is applied on the soil, oxidation process is observed on the surface of particles. The reason for the reported high CEC is the oxidation of aromatic carbon which leads to the formation of carboxyl groups [24]. With the increase in CEC the nutrients will remain attached to the soil opposing the leaching process. When highly oxidized organic matter attached with the surface it will create negative charge on the surface. As a result, positive charge on these sites gets decreased. However, the results from the studies showed that the effect of biochar is more expected on the soils having macro pores [25].

3.1.5 Stimulation of soil microflora and plant growth

Biochar provides a suitable habitat for a large and diverse group of soil microorganisms, although the interaction of biochar with soil microorganisms is a complex phenomenon. Addition of biochar along with phosphate solubilizing fungal strains promoted growth and yield of *Vigna radiata* and *Glycine max* plants, with better performances than control or those observed when the strains and biochar are used separately [26]. It was found that biochar increased the biological N_2 fixation (BNF) of *Phaseolus vulgaris* [27] mainly due to greater availability of micronutrients after application of biochar. It has also been reported that leaching of NH_4^+ was reduced with the application of biochar resulting to its higher availability for plant uptake [20]. Mycorrhizal fungi which were widely used as supplements for soil inoculums, often included in crop management strategies [28]. When using both biochar and mycorrhizal fungi in accordance with management practices, it is obviously possible to use potential synergism that can positively affect soil quality.

Study outline	Results summary	References
Cowpea on xanthic ferralsol	67 Mg ha^{-1} char increased biomass 150%; 135 Mg ha^{-1} char increased biomass 200%	Glaser et al. [19]
Soil fertility and nutrient retention. Cowpea was planted in pots and rice crops in lysimeters at the Embrapa Amazonia Ocidental, Manaus, Brazil	Bio-char additions significantly increased biomass production by 38 to 45% (no yield reported)	Lehmann et al. [20]
Comparison of maize yields between disused charcoal production sites and adjacent fields, Kotokosu watershed, Ghana	Grain yield 91% higher and biomass yield 44% higher on charcoal site than control.	Oguntunde et al. [29]

Table 2.
Summary of experiments assessing the impact of biochar addition on crop yield.

3.1.6 Improving crop productivity

The impactof biochar application is more prominent in highly degraded acidic or nutrient depleted soils. Several studies have reported positive responses of biochar on net primary crop production, grain yield and dry matter (**Table 2**). Little addition of charcoal (0.5 t ha^{-1}) have shown significant impact on various plant species, whereas higher rates caused plant growth inhibition [30]. Biochar if applied in combination with inorganic or organic fertilizers, can result into increased crop yields, particularly on tropical soils [19].

3.2 Environmental implications of biochar

3.2.1 Biochar and carbon sequestration

According to Turral et al. [31], agriculture generates around a fifth of the world's greenhouse gas emissions. The application of biochar is proposed as a novel approach to establish a significant, long term, sink for atmospheric carbon dioxide (CO_2) in terrestrial ecosystems. Biochar addresses two important sources of environmental problems, by sequestering CO_2 into the soil and by reducing water pollution through enhancing soil nutrient retention [32]. It was observed that biochar plays important role for emission of carbon and also essential to meeting global climate targets [33]. Biochar-bioenergy systems can play an important role in a global strategy favorably helps in carbon capture and storage at lower carbon prices whereas biochar addition to soils delivers significant increases in crop yields. Hence, effective use of biochar plays significant role in carbon sequestration.

3.2.2 Biochar and climate change

Now-a-days excessive amount of carbon dioxide is being released to the atmosphere due to the burning of fossil fuels and decomposition of biomass, which increases the carbon levels in the atmosphere day by day. Application of biochar helps in decreasing the emission of carbon dioxide as it has the ability to store 50% of the carbon from feedstock [34]. Biochar is highly stable and having the capacity to emit less carbon dioxide from organic decomposition significantly. So that it plays an important role in monitoring the release of methane and nitrogen dioxide from the soil, which are the major cause of climate change in recent days. This reduction in the release of nitrogen dioxide ensues because of the capacity of biochar to adsorb and retain the ammonium in soils and then lessen the availability of nitrogen for denitrification process. It is observed that in the fields, methane emissions were 34% higher from the fields which are treated with biochar. Though the emissions of nitrogen dioxide were found 40–51% less in soils than that of those soils which are not treated with biochar, thus global warming gases from soils decreases by amending soils with biochar [35].

3.2.3 Reducing water pollution

Application of biochar in soil also helps in the reduction of offsite pollution. It helps in increasing the retention of nutrients like phosphorous and nitrogen in soils, aid in decreasing the leaching of nutrients of soil in to the groundwater. Thus, it plays major role in saving the nutrients from erosion and nutrients availability for the cultivation of crop increases. By the pyrolysis of animal manures, a significant amount of reduction can be achieved in the mobility of phosphorous of animal manures [36] and this technique will help in reducing the weight and volume of the manures and will make the disposing off of waste easier. It also helps in conversion of the soluble inorganic phosphate present in the manure into the adsorbed phosphate in biochar.

3.2.4 Reduction of hazardous materials of environment

Biochar has the ability to sorb major environmental contaminants which are harmful for the soil. Sequestration of organic pollutants are being done by using biochar to alter their effects on the environment ultimately. Due to its struggling nature towards microorganisms and its astonishing sorption affinity, biochar acts as a critical binding phase for different organic pollutants in the environment. It was observed that the heavy metals present in the soil immensely affect the adsorption of organic pollutants on biochar and also interfere with their transport and fate. Biochar has the ability to adsorb organic contamination like persistent organic pollutants (POPs) as they have high affinity for biochar because it is naturally occurring [7].

3.3 Role of biochar on soil health

Soil health refers to the capacity of soil to perform a number of agronomic and environmental functions. Important among these functions are: agronomic/biomass productivity, response to management and inputs and resistance to biotic and abiotic stresses. With reference to agricultural land use, soil health refers to the capacity of the soil to sustain and support the growth of crops and animals while also maintaining or improving the quality of the environment. Maintaining an appropriate level of soil organic matter and biological cycling of nutrients is crucial to the success of any soil management regime. The decline in SOM contributes to several soil degradation processes including erosion, compaction, salinization, nutrient deficiency, loss of biodiversity and desertification, all of which are accompanied by a reduction in soil fertility [37]. Hence, the application of biochar and its impact on the quality of soil function is worthy of an exhaustive assessment.

According to Venkatesh et al. [38], transforming a low-value crop residue into a potentially high-value carbon source and its soil application has several important benefits. A brief review about these beneficial aspects are presented in **Table 3**.

3.3.1 Soil physical properties

Biochar as a soil amendment may improve the physicochemical properties of degraded or nutrient-depleted soils. The ability of biochar to retain soil water is a function of the combination of its porosity and surface functionality [39]. Porous

Physical properties	Chemical properties	Biological properties
• High negative charge of biochar promotes soil aggregation and structure. • Decreases bulk density, improves soil workability, reduces labour and tractor tillage and minimizing fuel emissions. • Positive effect on crop productivity by retaining plant available soil moisture due to its high surface area and porosity.	• Enhance the fertilizer use efficiency, reduce the need for more expensive fertilizers and improves the bioavailability of phosphorus and sulfur to crops. • Liming effect provides net carbon benefit compared to standard liming. • Reduce leaching of nutrients and prevents groundwater contamination. • Carbon negative process, stable carbon, longer residence period and reduces Green House Gas emissions from soil.	• High surface area, porous structure and nutrient retentive capacity of biochar provides favorable microhabitats by protecting them from drought, competition and predation. • Enhances the abundance, activity and diversity of beneficial soil bacteria, actinomycete and arbuscular mycorrhiza fungi.

Table 3.
Effect of biochar on physical, chemical and biological properties of soil.

internal structure of biochar increases soil porosity which helps to increase the surface area of soil so that water is better able to penetrate. Previous studies showed that application of biochar to infertile soils decreases soil bulk density, increases total pore volume and water holding capacity [7, 40]. Chen et al. [7] reported that biochar application decreased the tensile strength of soil cores, indicating that the use of biochar can reduce the risk of soil compaction.

3.3.2 Soil chemical properties

Biochar has potential benefits in improving the chemical properties of soils. Application of biochar to soil may improve nutrient supply to plants. Soil reaction (pH) is an important characteristic of soils in terms of nutrient availability and plant growth. Previous studies reported that soil pH was raised by high-pH biochar at about one-third the rate of lime resulting in increased calcium levels and reduced aluminum toxicity on red ferralitic soils [19, 20, 41]. Soil with a high CEC helps to hold or bind plant nutrient cations to the surface of biochar particles, humus and clay, so nutrients are retained rather than leached and therefore more available for uptake by plants [19, 20, 42]. Biochars derived from manure and animal-product feedstock are relatively rich in nutrients when compared with those derived from plant materials and especially those derived from wood [43, 44]. However, biochars in general may be more important for use as a soil amendment and driver of nutrient transformation than as a primary source of nutrients [45].

3.3.3 Soil biological sproperties

Biochar as a soil amendment is confronted with the challenge that it must benefit soil health as it can by no means be separated from soils once it is added. Soils can be viewed as complex communities of organisms that are continually changing in response to soil characteristics, climatic and management factors and especially in response to the addition of organic matter. However, compared to the addition of fresh organic matter, the addition of biochar to soils is likely to affect the diversity, abundance and activity of soil biotic communities [46]. Owing to its highly porous nature, biochar helps to provide habitat for microorganisms and also modify the biological functionality by altering the availability of substrate and activity of enzyme on, or around, biochar particles [47]. Biochar has the potential to affect microbial biomass and composition and the microbes are also able to change the properties of biochar [46]. Abujabhah et al. [48] reported that microbial abundance was improved after the addition of biochar. Biochar pores may provide physical protection for soil microorganisms. Soil reaction greatly influence microbial activity, diversity and abundance. The buffering capacity of the soil solution imparted by biochar CEC may also help to minimize pH fluctuations and maintain appropriate pH conditions in the microhabitats within biochar particles [49]. Studies have shown that biochar and fertilizer application increased microbial Biomass compared to mineral fertilizer. Microbial immobilization is an important mechanism to retain N in soils affected by leaching. Increased C availability stimulates microbial activity resulting in greater N demand, promoting immobilization and recycling of NO_3^- Biochar enhanced the PSM activity for P mobilization in phosphate rich soils and significantlyimproved the crop yield in P deficient soils [50]. The effect of biochar application on soil health under different soil types are summarized in **Table 4**.

Soil type	Biochar source	Rate of biochar addition (t ha^{-1})	Impact of biochar addition on soil health	Reference
Sandy Loam	Maize stover, Pearl millet stalk Rice and Wheat straw	20	• Maize biochar intensified soil available N and P. • Wheat biochar increased soil available K. • Rice biochar being relatively labile in soil enhanced the proliferation of microbial biomass.	Purakayastha et al. [51]
Sandy	Green cuttings	1, 10 and 40	• Increased CEC, total N and available P and Kwith biochar addition of 10 t ha^{-1}. • Increased water holding capacity of sandy soil by 6% and 25% with 10 and 40 t ha^{-1} application.	Glaser et al. [52]
Silty loam	Oak wood	7.5	• Reduced soil bulk density by 13% and increased soil-C by 7%.	Mukherjee et al. [53]
Calcareous	Rice husk and shell of cotton seed	30, 60 and 90	• Decreased soil bulk density, increased exchangeable K and water holding capacity at90 t ha^{-1}.	Liang et al. [54]
Clayey	Woody shrubs	5 and 10	• Decreased bulk density and improved saturated hydraulic conductivity as well as air capacity with 10 t ha^{-1} application.	Obia et al. [55]
Brown forest soil	Peanut shells	2.4	• Improved soil bacterial diversity, improved soil structure, increased soil pH and promoted effectiveness of soil nutrients.	Wang et al. [56]
Anthrosol	Wheat straw	10 and 40	• SOC increased by 57%, total N content enhanced by 28% in the 40 t ha^{-1}.	Afeng et al. [57]

Table 4.
Summary of the effect of biochar additions on soil health under different soil types.

4. Limitation

It is complicated to speculate the agronomic effectiveness of biochar with limited studies being conducted in different soil types, climatic belts and land use conditions. Heterogeneous nature as well as production cost of biochar for research and field application will continue to remain a major limitation until commercial-scale pyrolysis facilities are established. Some of the experimental constraints on use of biochar in agricultural systems are [38, 58]:

i. Unavailability of sufficient quantity of biochar for large scale use

ii. Susceptibility of dry biochar to wind erosion

iii. Non-adoption of biochar by local farming communities

iv. Unavailability of adequate farm labour

v. Expensive wage costs incurred for collection and processing of crop residues

vi. Lack of appropriate farm machinery for on-farm recycling of crop residues

vii. Inadequate incentives for recycling of crop residue.

Other limitations involve contamination risk of biochar (PAHs, heavy metals, dioxins) when contaminated feedstocks are used or when inappropriate process conditions are used for biochar preparation such as temperature greater than 500°C.Removal of crop residues from the field for biochar production results in its reduced incorporation into soils, hampering many soil properties. In certain cases, extremely high rate of biochar application produces negative effects on earthworm survival rates [59].

5. Recommended practices for use of biochar in agriculture

Nature of crop residues for biochar production: Freshly harvested, under-utilized dry crop and agroforestry residues should be used for biochar production. Use of crop residues grown on toxic chemical and heavy metal contaminated site should be avoided.

Location and operation of biochar kiln unit: The biochar kiln unit should be located near to the crop and agroforestry residue generating locations to providea management solution and minimize handling and transportation loss and costs. The kiln unit should be operated in an open space with sufficient atmospheric aircirculation, ideally away from any other structures. Precautions should be maintained while opening and closing of kilning unit during the cooling period.

Preparation of biochar: The fresh biochar needs to be 'cured' overnight with exposure to open air. It is advisable to store the biochar outside under shelter, away from buildings, in a cool, dry wellventilatedopen spot and grind to powder just before its use. The biochar should be transportedto the application site in a sealed container or in a closed plastic bag.

Application of biochar: It is better to apply biochar as close to ground as possible on mildwindy day to avoid drift loss by wind.

Protective clothing such as insulated gloves or gunny rags, masks or cloths should be used whenever possible while handling kiln and biochar.

6. Future prospects

Although biochar utilization has gained much attention in recent years, there still lies a huge knowledge gap that needs to be addressed. The ultimate fate of biochar under field conditions and its long-term influenceon soil quality are questions which remains unanswered. The influence of biochar on soil physical and chemical properties as well as the microbial communities, needs to be further explored especially in accordance to changes in biogeochemical cycles [60]. Researchers need to searchsolutions to reduce GHG emission to a large extent, when soils are amended with biochar [61]. Focus needs to be paid on full-scale outdoor trials of biochar as a way to restore contaminated soils and evaluate how long biochar retains the metals as it ages in the field [15]. Lastly, better understanding of biochar preparation needs to be done with different feedstock materials and pyrolysis processes to target specific soil deficiencies [60].

7. Conclusion

Ever-increasing population has paved the way to agricultural land depletion which needs to be controlled by adopting sustainable crop production practices. Direct incorporation of crop residues into agricultural soil conserves soil nutrients as well as organic carbon contentbut initiates considerable crop management problems by delayingthe decomposition process. Conversion of crop residues to biochar by thermo-chemical process (slow pyrolysis) is an attractive, economical alternative approach for effective management and disposal of these excess crop residues, whichotherwise are being used inefficiently. Addition of biochar to soil is one of the best practices to overcome any biotic/abiotic stress caused, such as heavy metal toxicity, soil acidity, nutrient unavailability etc. and to increase the crop productivity. From the agriculture point of view, application of biochar as a soil conditioner generates numerous benefits, such as improvement of the physical, chemical and biological properties of soils, and this in turn contributes to an increased crop yield. Owing to their physicochemical properties, biochar can be used for soil carbon sequestration, reduction of the bioavailability of contaminants affecting living organisms as well as for water treatment. The persistence of biochar effects on soil processes and mechanisms remains to be resolved under realistic field conditions. Therefore, it is recommended to use biochar as a soil amendment for enhancing soil health and environmental condition as well as long-term carbon sequestration.

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