A Review on the Applications of Biochar in Agricultural Farms: A Low Carbon Emission Technology

Abstract

Improving the condition of the soil is essential for successful agriculture since it increases crop output and soil fertility. Applying biochar to the soil can boost crop yields and soil fertility. Biochar is a solid carbon-rich substance made by pyrolyzing biomass, which includes trash, wood, and agricultural crop leftovers under low oxygen conditions. Because biochar has potential uses in waste recycling, soil nutrient retention, and greenhouse gas emission reduction, it is significant for sequestering carbon. Over the last two decades, biochar has received substantial attention in agriculture and the environment. Agriculture soil productivity has long been increased by the application of synthetic fertilizers, some of which leached into the environment and released greenhouse gases (GHG). Improving soil microbiology and water retention, as well as increasing fertilizer efficiency, are some of the basic problems facing agricultural practices. Biochar is becoming more and more popular as a soil supplement to increase crop yields and sequester carbon. Biochar is one of the many conservation agricultural techniques that can be used to improve soil fertility, and crop productivity, and slow down global warming. It is also a readily available and important input for sustainable agriculture. Furthering global food security, biochar may improve soils' ability to produce crops under various biotic and abiotic stress. This review examines the numerous uses of biochar to guarantee the long-term, safe enhancement of soil fertility. An overview of the characteristics, manufacturing process, and applications of biochar in agriculture is given in this review. Researchers, farmers, and academics interested in using biochar might find this review to be a helpful resource.

Keywords: *Agriculture, Biochar, Conservation, Productivity, Soil fertility, Technology*

1. Introduction

Plant residues and agricultural wastes pose a serious environmental threat to the world since they contribute to the rise in greenhouse gas emissions. As a result, several researchers made use of these wastes in various ways, including biochar, organic fertilizers, and soil mulching (Ganesapillai *et al*., 2020). At temperatures below 700 °C, biochar is a material that is separated from its constituent parts by a process of thermal conversion, resulting in a restricted delivery of oxygen. It is a multipurpose renewable energy source that can provide power, heat, and liquid biofuels (Ghosh *et al*., 2020). Pyrolysis-produced charcoal, or biochar, has a porous structure that is kept up well and has various inorganic nutrients, a sufficient number of functional groups, and carbon components that are stable. In contrast to other organic nutrient types, biochar is a persistent soil nutrient and is essential for mineralization and adsorption. It can improve the quality of the environment and make more nutrients available in the soil (Azzi *et al*., 2021). It is a high-carbon material that further reduces the likelihood of environmental pollution and degradation while serving as a soil supplement in agricultural areas. Biochar production is contingent upon three factors: the type of biomass [e.g] rice hulls, food wastes, animal byproducts etc. The manufacturing technique [e.g] pyrolysis, thermal carbonization, gasification, and the manufacturing process [e.g] methods, temperature (Cisse *et al*., 2022; Ghosh *et al*., 2020).

Biochar has the potential to be extremely beneficial in the fight against climate change because of its capacity to sequester carbon in a form that is resistant to climate change, lower emissions of potent greenhouse gases like nitrous oxide and methane, boost crop yields and fertilizer efficiency, repair degraded lands, and remove organic contaminants (like pesticides, herbicides, dyes, pharmaceutical/personal care products, perfluorooctane sulfonate, humic substances, and N-nitrosomodimethylamine) from water sources (Ray and Bharti, 2023). It is known that adding biochar to soil improves its structure, increases plant nutrient uptake, promotes microbial growth, and boosts nutrient retention. The total disintegration of biochar may take several years due to its refractory nature and slow rate of breakdown in soil (Manikandan *et al*., 2023). The increasing literature suggests that biochar applications could be a critical input for sustaining production while also lowering pollution and reliance on fertilizers. It has also recently been shown that adding biochar can improve soil fertility, water-holding capacity, and nutrient uptake while sequestering carbon and lowering greenhouse gas emissions (Cisse *et al*., 2022; Ganesapillai *et al*., 2020). More recently, multiple studies have demonstrated that adding biochar to soils can enhance crop yields while also alleviating plant stressors caused by drought and heavy metals. Despite the increasingly diverse acknowledged benefits of biochar applications, there remain numerous barriers to its usage in sustainable agriculture (Rex *et al*., 2023). A cause for concern is the vast range of variations found in biochars, ranging from pH and nutrient availability to chemical and physical qualities that rely on the kind of feedstock, pyrolysis conditions, addition of other chemicals or level of powdered fineness (Enaime *et al*., 2023). The relationship between the qualities of biochar and its effects on soil properties, plant growth, yield, and resilience to biotic and abiotic challenges has to be properly evaluated scientifically since an understanding of biochar has advanced recently (Manikandan *et al*., 2023). With an increasing amount of literature on some potential implementations of biochar in sustainable agriculture, the overall aim of the present review focuses on the biochar applications in the agriculture farm.

2. Biochar Production Process

There are numerous methods for producing biochar, and the process has a significant influence on the final product's properties. The production process of biochar is depicted in Figure 1 and different biochar production processes are described below:

2.1 Pyrolysis

Pyrolysis is the application of heat decomposition to produce high-carbon components such as biochar; hydrothermal carbonization (HTC) is the term for this process when it is carried out on a subcritical aqueous substrate. The yield and composition of the pyrolyzed product are influenced by many pyrolysis parameters, including the temperature and rate of heating applied to the material (Danesh *et al*., 2023). The temperature and heating rate have a range of 400 to 600 °C and 5 to 25 °C per minute, respectively. The ultimate yield fell with increasing temperature and heating rate, and vice versa. This method uses an exit pipe that is connected to many cooling condensers to carry out the finished product (Li *et al*., 2023). This technique involves several reactors, including paddle pyrolysis kilns, agitated drums, wagon reactors, and sand-rotating kilns. As the cracking response gets better in this process, it produces less liquid. Pyrolysis can be carried out in both batch and continuous modes, depending on the desired ultimate yield (Danesh *et al*., 2023; Iwuozor *et al*., 2023). Because continuous input is possible in the continuous mode, pyrolysis can be improved over the batch method. Batch mode includes cheaper, easier-to-design, and simpler-to-operate brick, concrete, and metal kilns as well as earthen and mound kilns that can run at temperatures between 300 and 500 °C (Blenis *et al*., 2023). Two categories of pyrolysis exist based on the specified heat rate, pressure, temperature, and residence duration. Lignin is transformed into non-condensable gas in hemicelluloses, which is subsequently transformed into condensable organic vapors and aerosols, bio-oil, and biochar at the right temperature for breakdown (Xie *et al*., 2022). Because their dry weight content is typically higher than that of other plants, C4 plants are widely used in Europe to produce biochar (Danesh *et al*., 2023). Different types of pyrolysis are described below:

2.1.1 Dry Pyrolysis

Dry pyrolysis is the process of thermally breaking down a dry, chemical-free substrate at a high temperature in an anaerobic environment. This process involves several variables, such as high temperature, heating rate, vapor-solid interaction, heat transfer rate, pressure, etc. (Wang *et al*., 2020) The overall production is influenced by several feedstock parameters, including lignin, cellulose, and hemicellulose mixture, size, structure, physical character, and ash concentration (Panahi *et al*., 2020).

2.1.2 Slow Pyrolysis

A promising carbon-negative process for producing biochar from different bio-stuffs is slow pyrolysis, which converts recalcitrant carbon into a variety of products while lowering the amount of CO_2 in the environment. The temperature range for slow pyrolysis is 350-400 °C to 600-700 °C, with a heating rate of 5 °C per minute. For cellulose and hemicelluloses to break down, heat is applied (Sakhiya *et al*., 2020). Use agricultural waste for slow pyrolysis. The solid product of biochar is maximized through slow pyrolysis, which can be done in a lab setting with slow pyrolysis equipment. After grounding, the entire ground product is raised to apply a pre-drying treatment, resulting in a moisture-free product (Seow *et al*., 2022). During pyrolysis, the heating efficiency is reduced when the product contains moisture. Ground materials are dehumidified by heating them to 105 °C in a traditional oven until the sample's weight stays constant (Li *et al*., 2023). Torrefaction is a process where pre-treatment is performed on the material to create carbon-rich products. Hydrothermal pyrolysis yields a high hydrochar yield, while slow pyrolysis yields a char yield. Pre-pyrolysis takes place before solid decomposition in slow pyrolysis to produce a product (Sakhiya *et al*., 2020). Air pollution is caused by the discharge of volatiles into the atmosphere by conventional biochar extraction procedures such as earthen, brickwork, and steel kilns. Retorts, converters, and kilns are examples of reactors used in slow pyrolysis. Several researchers have used slow pyrolysis methods to turn agricultural wastes including wood sawdust, rice waste, and maize stover into biochar (Li *et al*., 2023; Seow *et al*., 2022).

2.1.2 Fast Pyrolysis

Rapid pyrolysis can increase bio-oil output by up to 75% when it is carried out at 800 to 1300 °C at a heat rate of 200 °C/min for no more than 10 sec. The reactors used in this procedure include ablative reactors, rotating-cone reactors, bubbling fluidized beds, and circulating beds (Yaashikaa *et al*., 2020). To get the most liquid product possible, fast pyrolysis is performed. Hardwood, grass, and other agricultural leftovers are produced in greater quantities when softwood is used, along with the liquid product (Kwoczynski and Čmelík, 2021). Anaerobic conditions from 10 to 100 °C are reached in 0.5–2 seconds during fast pyrolysis when biomass is broken down. Ablative reactors, rotating cones, vacuum, entrained flow, and fluidized beds are among the reactor types used in rapid pyrolysis (Patra *et al*., 2021).

2.1.3 Microwave Assists Pyrolysis

One of the most effective thermochemical procedures is microwave-assisted pyrolysis. While the microwave undergoes pre-treatment before heating, the conventional method of pyrolysis is carried out as a standard heating operation (Xie *et al*., 2022). Warm water, the liquid byproduct of traditional processing, is a non-compressible gas, while the byproduct of conventional is pyrolyzed gas. Because secondary reactors are not formed, it addresses the drawbacks of traditional biochar manufacturing and enhances product quality (Danesh *et al*., 2023). The process, which is carried out at 2.45 GHz and 915 MHz as required by international agreement, is also referred to as an electric volumetric heating method. It is highly efficient, emits little pollutants, and conserves energy (Sakhiya *et al*., 2020).

2.1.4 Hydrothermal Carbonization (HTC) or Wet pyrolysis

The process of thermally breaking down an organic substrate in a subcritical aqueous medium to produce a high-carbon product is known as hydrothermal carbonization or HTC. The ideal conditions for biochar are 180 to 250 °C temperatures, 2 to 10 MPa of pressure, and water (Gabhane *et al*., 2020). The primary factor in the carbonization and breakdown of lignin, cellulose, and hemicelluloses at lower temperatures than in dry pyrolysis is the aqueous substrate used in HTC. Thus, HTC is especially well-suited for processing high moisture content feedstocks or waste residues, such as aquatic plants and algae (Zhao *et al*., 2021). These processes dehydration, polymerization, hydrolysis, aromatization, and decarboxylation break down a hydrocarbon into smaller pieces while maintaining a substrate that resembles lignite, the end substrate. Levulinic acid, organic acid, hydromethyl furfural, glucose, and other organic acids are among the chemicals used in this process (Pandey *et al*., 2020). Intermediate products have a variety of uses in the industrial sector. By getting rid of microbes and organic pollinators, it lessens the dangerous qualities of different chemicals. Biochar, liquid products, and gaseous products are produced by HTC, which is carried out in water at pressures lower than 10 bars (Li *et al*., 2020). At reduced energy levels and temperatures, it can deliver output quality that is more significant more quickly. At 180–250 °C underwater, it is the most economical method and is especially appropriate for small-scale, farm-based biochar production. This process involves several variables that impact the ultimate output, which ranges from 40 to 70% biomass (Gabhane *et al*., 2020; Pandey *et al*., 2020).

2.1.5 Gasification

Gasification is the process of converting a carbon source using a control oxidizing agent (steam, oxygen, and air) to a gaseous product (syngas) at a temperature below 70 °C. Less than that of pyrolysis, the ultimate yield is only approximately 10% of the biomass (Rex *et al*., 2023). Reactant/biomass ratio, temperature of the reaction, length of residence, particle size, and pressure are agents in this process. The one that influences the total yield among them is temperature. Higher amounts of producer gas, sometimes referred to as syngas ($CO + H_2$), can be obtained using a gasification process (Ray and Bharti, 2023). Pyrolysis-producing gases were once utilized for home heating, cooking, lighting, and other purposes. Plants are exposed to two portions during gasification. Gasification takes place in the first portion, while syngas are cleaned and cooled in the second. The auger reactor type is utilized for the continuous production of biochar (Zhao *et al*., 2021).

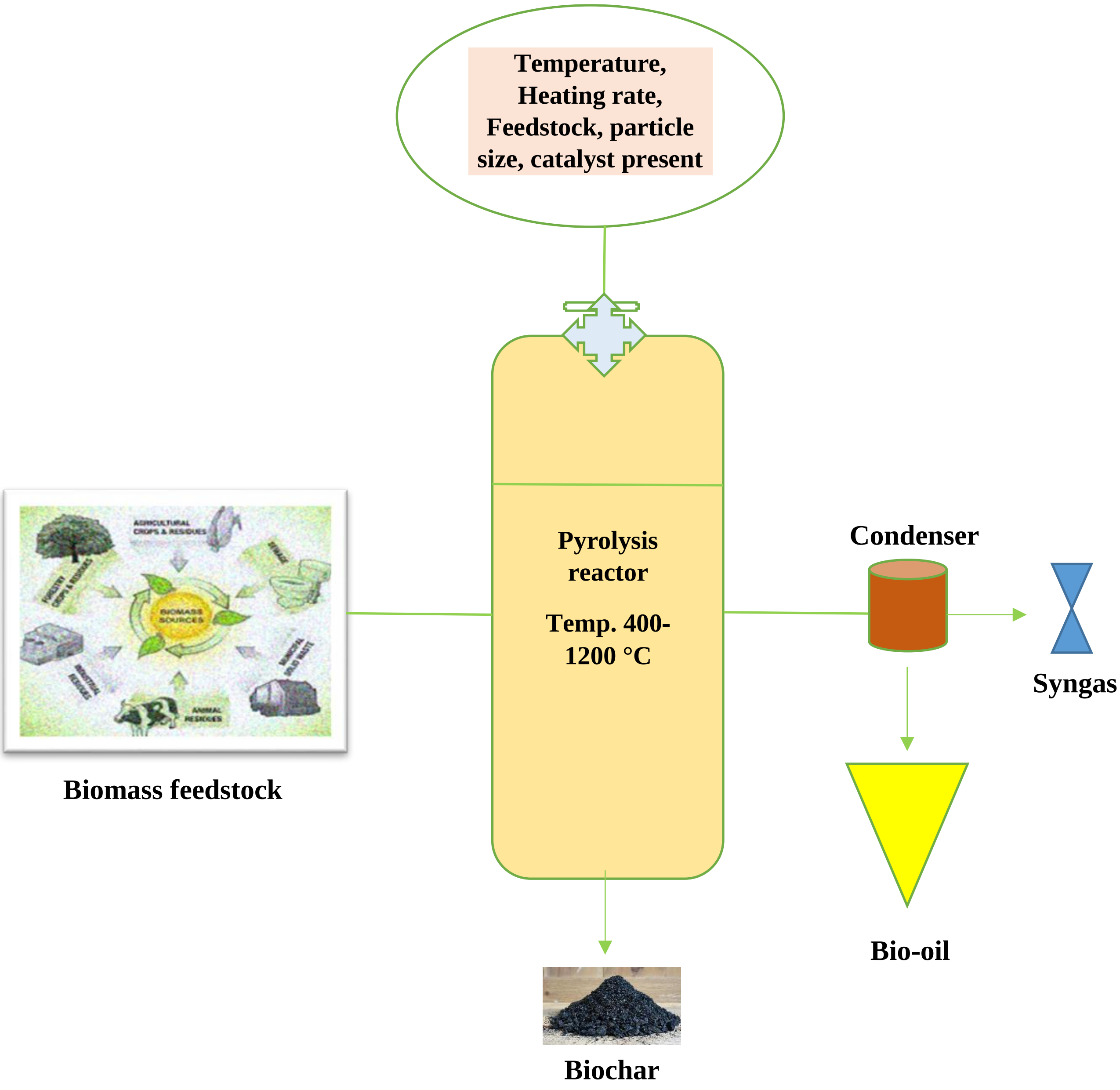

Figure 1. Production process of biochar by pyrolysis

3. Applications of Biochar

Biochar has a greater proportion of inert carbon components, carbon groups containing oxygen, and a large surface area. It also has a pore structure that increases the soil's capacity to sequester carbon, reduce greenhouse gas emissions, improve structure, and raise crop yields (Guo *et al.*, 2016). The application of biochar is influenced by its composition and characteristics. Biofuels can be produced using biochar as well. The three main techniques for applying biochar to soil are top dressing, depth application, and topsoil inclusion (Lu *et al.*, 2020). The addition of biochar improves the permeability, fertility, and water retention of soil. Large amounts of nutrients were also carried by its high charge density, which changed the characteristics of the soil and increased crop productivity (Zhao *et al*., 2021). Different applications of biochar are described in Figure 2 and below:

3.1 Improves the Soil Properties

Soil structure is improved when biochar is applied to agricultural soil. The agricultural soil can absorb more nutrients because of the enhanced physiological, chemical, and biological characteristics of the soil. Biochar also readily eliminates all the heavy metals through adsorption, even though several different techniques have been developed (Sizmur *et al*., 2016). Organic pollutants and harmful substances are also removed from soil and plants by adsorption. It has been discovered that using biochar helps to break down or eliminate organic pollutants such as diethyl phthalate, p-nitrophenol, halo hydrocarbon, polychlorinated biphenyls, and 2-chlorobiphenyl (Amin *et al*., 2016). An innovative way to improve soil water retention, filtration, soil moisture availability, and nutrient retention is the recent application of biochar (Lu *et al*., 2020).

3.2 Enhances the Soil Fertility by Improving Nutrient Availability

Improving fertility by increasing nutritional availability. Applying biochar to the soil can restore soil fertility as well as improve its physical, chemical, and biological qualities. Table 1. describes the different nutrients and their benefits on biochar. Soil salinity can reduce crop yield by slowing roots' absorption of soil nutrients and water. Biochar lowers soil salinity, improves ion exchange capacity, and increases significant and minor soil nutrients (Yuan *et al*., 2023). All of the sodium in the soil is absorbed, increasing the exchangeable magnesium and calcium in the soil, which replace the sodium and reduce its alkalinity. By acting as a nutrient source, biochar can alter the nutrient cycle and nutrient reactivity in the soil as well as increase and decrease nutrient mobility and availability (Tag *et al*., 2016). Because biochar includes most of the required elements for plants, it can be used as a multiple source of nutrients. Additionally, it lessens the amount of nitrogen fertilizer that leaches from the soil. Moreover, it has a high adsorption capacity that enables the soil to absorb phosphorus, nitrogen, potassium, and organic materials (Zhu *et al*., 2023). When added to calcareous soil, biochar (BC200) increases the quantity of available Fe, Cu, and Zn and boosts the inorganic nitrogen content of the soil (Yuan *et al*., 2023).

Table 1. Different Soil Nutreints and their Health Benefits in Biochar

Soil nutrients	Benefits	References
Nitrogen, Sodium, Potassium, Phosphorous	Improves soil fertility, photosynthesis, growth and yield significantly	Li *et al*., 2023
Potassium, Phosphorus, Calcium	Improves soil aggregation, water retention, pH, and microbial activities, soil quality	Nepal *et al*., 2023
Potassium, Phosphorous, Sodium, Nitrogen	Improves soil structure, High nutrient use efficiency (NUE), improves water-holding capacity (WHC)	Alkharabsheh *et al*., 2021
Phosphorous, Nitrogen, Sulphur, Carbon	Enhances crop productivity, improves soil nutrient supply, increases element cycling	Hu *et al*., 2024
Organic carbon, Nitrogen, Phosphorus,	Enhances soil quality, improves yield, reduces exchangeable acidity, increased effective cation exchange capacity in soils	Mensah and Frimpong, 2018
Potassium, Phosphorous, Nitrogen, Sodium	Improves the pH, increases the organic carbon content, enhances nutrient retention, increases water-holding capacity, increases microbial biomass	Beusch, 2021

3.3 Soil Remediation

Soil contamination from residential and industrial operations, as well as different chemicals, compounds, or substances that either directly or indirectly alter the activities of non-targeted microorganisms, has become a major global issue in recent times. Using biochar to clean up polluted soils is one method of eliminating contaminated soil (Uday *et al*., 2022). Made from trash, it is a cost-effective and environmentally friendly way to restore the soil. Additionally, it lowers the amount of contaminants in the soil because of its vast surface area, better water-holding capacity, and extremely porous nature (Senadheera *et al*., 2023). This is supported by the fact that several studies have shown that immobilization techniques, such as the use of biochar, can effectively remediate soils for heavy metals and metalloids. The biochar derived from *Carya spp.* can effectively adsorb and decrease the leaching of clomazone and sodium bispyribac in soil (Cao *et al*., 2017).

3.4 Encourages Microbial Activity in the Soil

By changing the physical and chemical characteristics of soil, applying biochar affects the soil's capacity to serve as a carrier for the establishment of microorganisms. Crop production potential, nutritional status, and the decomposition of organic materials are all impacted by soil microbe activity (Zhu *et al*., 2023). Biochar can stimulate soil microbial activity. Because it gives the microorganisms a medium, biochar promotes microbial growth in the soil. The use of biochar affects the habitat and activities of other soil organisms, such as mycorrhizal fungus, which directly improves the quality and health of the soil (Cao *et al*., 2017). By adjusting the suppression of arsenic and ferric ions, the biochar generated from fresh biogas has a positive influence on bacteria (Uday *et al*., 2022).

3.5 Crop Improvement

Crop production and yield are positively impacted by biochar. It improves the crops' ability to access and utilize nutrients. Studies in the literature have shown that using biochar increases crop production by 10%. By removing salt from the soil, biochar increases yields by facilitating nutrient availability (Conte *et al*., 2016). Additionally, biochar may be able to control or eradicate pests and illnesses from agricultural fields. Applications of 3–5% biochar can impede the growth of pests and fungal diseases. Moreover, biochar improved crop output and showed a promising role in weed control in faba beans (Kumar *et al*., 2023). Furthermore, a multitude of field tests and pot experiments have demonstrated that adding different kinds of biochar to the soil enhanced the growth and yield of a range of crops, including *Zea mays*, *Cucumis sativus*, *Phaseolus vulgaris*, *Fragaria × ananassa*, *Solanum lycopersicum*, *Citrullus lanatus*, and *Piper nigrum* (Gasim *et al*., 2022).

Table 2. Role of Biochar in Crop Improvement

Benefits of crop improvement	References
Increase crop productivity, soil fertility, improve agricultural crop residues, wastes, and wood, maintain carbon sequestration	Yadav *et al*., 2023
Increasing carbon sequestration in soils, improves soil quality, greenhouse gases, nutrient retention, pesticide decontamination, water management, crop yield, economy	Losacco *et al*., 2023
Improves bioenergy, carbon sequestration, soil quality, greenhouse gases, nutrient retention, water management, crop yield and economy	Majumder *et al*., 2023
Enhance soil quality attributes, improve soil physical, chemical, biological properties	Ali *et al*., 2024
Biochar promotes plant growth, increases crop yields, enhances microbial activity, promotes sustainable agriculture, sequestering atmospheric carbon, improves soil quality	Kabir *et al*., 2023
Maintain sustainable approaches in agricultural crop production, improve carbon-rich material, improves crop growth and yield	Rawat *et al*., 2019

3.6 Climate Change Mitigation

One of the most significant environmental problems of the 21^{st} century is global warming, caused by increasing greenhouse gas (GHG) emissions, and the carbon (C) cycle plays a crucial role in both its cause and its mitigation. Biochar has outstanding physical and chemical substances for use in different fields to improve eco-natural quality (Kamali *et al*., 2022). Biochar can be utilized as a catalyst for the degradation of contaminants because gathers transition metals. Appropriate management of organic wastes can indirectly reduce methane emissions from landfills, industrial energy usage, and other greenhouse gas emissions that are indirectly useful for mitigating climate change (Karimi *et al*., 2020). Mitigating excessive nutrient export from agricultural watersheds may be accomplished by pyrolyzing animal manures or by using suitable biochars to reduce the leaching of phosphates and nitrates found in soil or co-applied manures. The need to see biochar management as a system rather than as a discrete part is demonstrated by the potential reduction in greenhouse gas emissions (Amalina *et al*., 2023). System CO_2 emissions are reduced by biochar, which is crucial for reducing climate change because it has less mineralization than the raw material used to make it. Therefore, there are fewer CO_2 emissions because biochar is firmly bonded to soil particles. The application of biochar in carbon sequestration and greenhouse gas reduction two crucial areas of mitigating climate change has been studied (Kamali *et al*., 2022; Karimi *et al*., 2020).

3.7 Carbon Sequestration

Biochar was first proposed as a soil additive to retain carbon in the soil, hence increasing carbon sequestration because its carbon component is generally stable. A reasonably stable type of carbon known as "biochar" has the potential to serve as an effective long-term carbon store, reducing greenhouse gas emissions significantly (Huang *et al*., 2023). When biomass is used in conjunction with waste management techniques and strategies, it may be able to store organic carbon that would otherwise be burned or composted away to build minerals over time. As such, it could be a suitable replacement for current waste disposal systems (Fdez-Sanromán *et al*., 2020). Some biochar-based composites have the potential to enhance the stability and biomass carbon retention of virgin biochar. Biochar made from residual biomass from the food processing and agricultural sectors has a favorable impact on soil health and the environment while also helping with long-term carbon sequestration (Paz-Ferreiro *et al*., 2016).

3.8 Mitigate Greenhouse Gas Emissions

Global biochar use is thought to be able to cut greenhouse gas emissions by 12%. Even while biochar alone can reduce global greenhouse gas emissions, a recent study suggests that using biochar composites in the soil instead of virgin biochar may help alleviate climate change in two ways (Karimi *et al*., 2020). First, it has been proposed that mixing compost with biochar will enhance decomposition capacity by contributing more stable carbon and yielding a valuable byproduct (biochar-compost mix), which would offset any potential disadvantages of the pyrolysis biochar technology (e.g., low macronutrient content, composting system, and CH_4 emissions capacity) (Conte *et al*., 2016). Second, biochar has been associated with increases in soil organic matter and a decrease in the emission of greenhouse gases (GHGs) with a high potential for global warming, such as CH_4 and N_2O. In actuality, a biochar system may need to grow more plants or emit fewer greenhouse gases from the soil to have a better emission balance than if biochar were used as a charcoal fuel (Kumar *et al*., 2023). By promoting methanotroph (methane-consuming bacterial) communities and reducing the diversity of methanogens (methane-producing bacteria), biochar contributes significantly to the reduction of methane emissions from rice fields (Gasim *et al*., 2022).

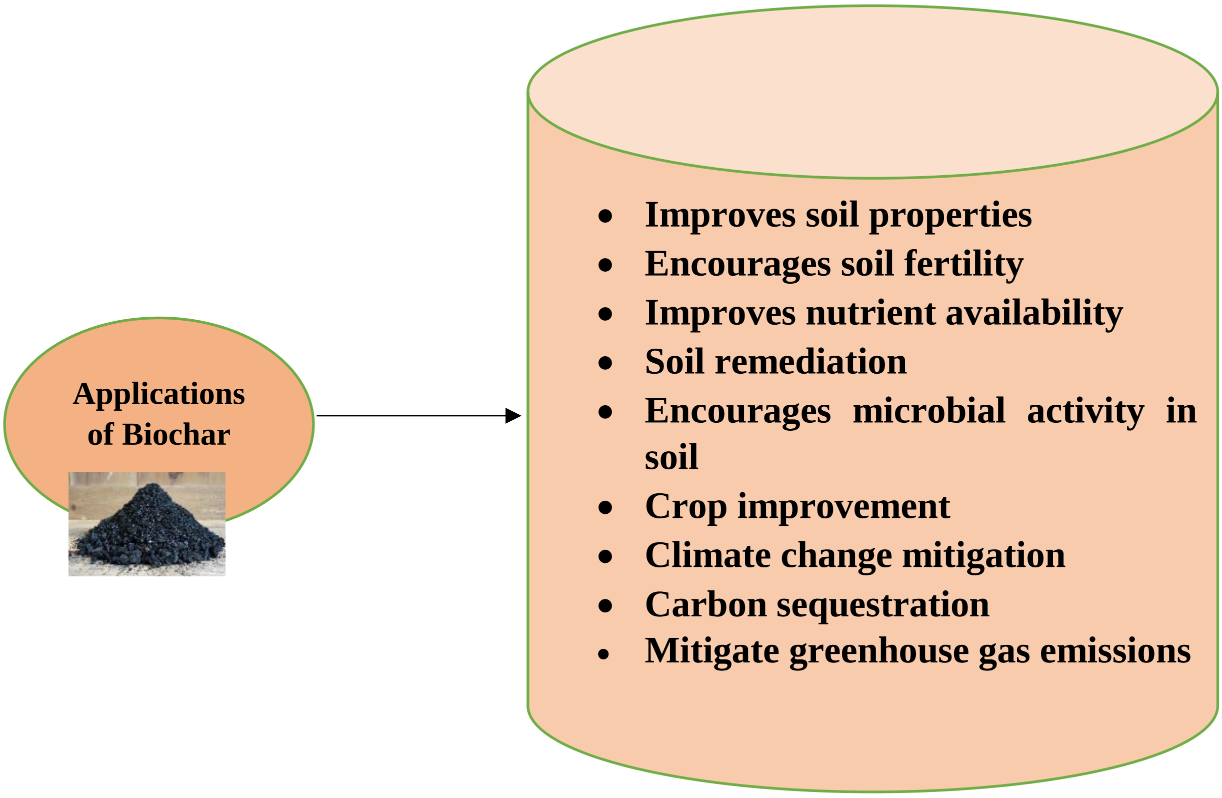

Figure 2. Different Applications of Biochar

4. Advantages of Biochar

The majority of biochar engineering methods are more workable or economical than the conventional carbon activation procedure. Moreover, fuel cells, supercapacitors, and novel composites like metallic nanoparticles can be produced using biochars as a substrate for catalysis (Hamidzadeh *et al*., 2023). Biochar is becoming more and more popular as a viable alternative remediation agent for a variety of environmental contaminants, including heavy metallic ions, organic pollutants, and even nutrients, because of its low cost and easy access to feedstock materials, such as agricultural and forestry wastes. Carbon-rich substances called biochars enhance soil quality and increase crop yields (Patel and Panwar, 2023). The raw materials used to make biochars are derived from agro-industrial leftovers and primarily include cellulose, hemicellulose, lignin, and a small amount of inorganic minerals. For a longer period, biochar can keep water and nutrients in the top layer of soil, limiting nutrient loss from the crop root zone and thus increasing crop productivity (Sharma *et al*., 2023). Biochar has been used in the energy, environmental, and agricultural domains to advance sustainability. The manufacture of biochar, an emerging technology, can improve national food security and trap carbon to slow down climate change (Hamidzadeh *et al*., 2023; Patel and Panwar, 2023). ZVI (zerovalent iron) particles are advantageous for the environment and the economy and are also supported by biochar. Locally accessible and reasonably priced resources such as wood products, agricultural wastes, manure, etc. can be used to generate biochar (Ghosh *et al*., 2020).

4.1 Disadvantages of Biochar

Herbicides and soil nutrients are among the agrochemicals that are bound and rendered inactive by the applied biochar in the soil. Numerous biochars evaluated here reduced soil and N_2O production while also slowing the net CH oxidation rate in the soil. Biochar contains several phytotoxic chemicals that may hinder plant germination (Campion *et al*., 2023). The physiochemical properties of soil are influenced by biochar; it decreases the porous structure while increasing bulk density and porosity. Because of the EC and pH, too much biochar put into the soil affects germination and biological processes. The low mechanical strength and dusty character of biochar provide problems, particularly in agricultural soil where significant volumes are frequently lost to wind or rain as a result of soil application conditions (Akbar *et al*., 2023). Biochar is absorbed into the soil once it is applied, making it impossible to remove. Because of its fine-grained texture, biochar cannot be used to generate energy in combined heat and power plants because it would be difficult to evenly feed thermal energy systems with the required amount of biochar (Ghassemi-Golezani *et al*., 2023). There is always a possibility that dangerous materials found in biochar, like heavy metals, could be released. Not all organic waste can be made into agriculturally beneficial biochar. The reason for this is that certain production methods and feedstocks produce biochar that is prone to microbial deterioration and ineffective in storing nutrients (Shen *et al*., 2023).

5. Conclusion

Biochar can improve crop growth, productivity, and soil properties. These benefits include higher growth and yield, heavy metal adsorption, greater water-holding capacity, and favorable plant physiological responses. Biochar has enormous potential for application in large-scale agricultural production. Initial research indicates that employing biochar can boost crop productivity and soil fertility while minimizing the consequences of climate change. There are many different types of biochar, and they can affect soil characteristics, crop growth, and productivity in different ways. Numerous impacts, such as increased growth and production, heavy metal adsorption, water-holding capacity, and physiological responses in plants, have been demonstrated to be advantageous. Crop growth and yield are significantly impacted by the rate of biochar addition; however, this varies depending on the crop and culture system. When it comes to crop development, biochars offer enormous promise for both greenhouse pot production and large-scale field production. But to encourage the use of biochar as a soil supplement and as a possible weapon against climate change, more investigation, development, and demonstration of its production and application are needed.

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