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Bamboo biochar as a viable source for carbon sequestration and climate change mitigation

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Abstract

The increase in emission of green house gases due to the rapid urbanization and industrialization is showing harmful impact on climate. The temperature is rising since the industrial era started but now the scope is very constraint, a minimal increase in temperature is extremely challenging. Carbon capture is one of the necessary steps to limit the changes in climate due to rise in temperature. The adsorbents which are cost effective and perform evidently draw more attention. The concept behind the carbon capture is to divert a portion of carbon cycle into carbon sink in a stable form of carbon. Biochar, a solid carbonaceous and porous material produced through pyrolization can use as soil amendment to serve a soil carbon sink and store carbon for a long time. Besides high stability, the growth rate of new biomass must be same as the rate of turning biomass into biochar because photosynthesis is responsible for capturing atmospheric CO_2 and its conversion to the plant biomass suitable for pyrolyzation. As bamboo is a fast-growing perennial, giant grass with high biomass production, can be used for the production of biomass to produce biochar. Moreover, bamboo biochar can improve soil texture and check upon harmful effects of contaminants on plant by stabilizing them into soil. However, bamboo biochar has not been explored to that extent despite its good CO_2 uptake. Bamboo biochar can be a potential solution to carbon sequestration with low cost, low regeneration temperature and excellent adsorption capacity.

Keywords Bamboo; Carbon Sequestration; Biochar; Climate change

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1. Introduction

Recently, the world is facing major challenges like global warming and climate change, affecting weather patterns, ecosystem and human livelihoods (Farooq et al. 2022). The temperature of oceans and lower atmosphere of earth is rising due to global warming and now it has been acknowledged globally as an indubitable fact and a substantial threat to get along with in future (Rashid et al. 2020). According to IPCC, the average temperature will increase by 1 to 2.5^{0}C by 2030 (Senitan et al. 2022). The human activities like fossil fuel combustion and deforestation result into release of excessive carbon dioxide (CO_2) and other greenhouse gases (GHGs) in environment that is responsible for increased global warming leading to climate change (Rashid et al. 2020). IPCC (2022) concluded that the agriculture, land use sector and forestry contribute about one-quarter of global GHGs emission. Additionally, the increasing population requires land for accommodation and food leading to the expansion of agricultural land use and intensification of farming practices and deforestation that release CO_2 stored in trees and soils contributing to the increased atmospheric CO_2 (Roberts 2016). It is estimated that 80% of deforestation is due to the agricultural expansion results of increasing population (Raihan et al. 2022). For effective climate change mitigation, both the reductions in emission of green house gases and elimination of atmospheric CO_2 have to be considered (Field and Mach 2017). The reduction in carbon dioxide emission can be gained by better management of agricultural soils to control the release of GHGs like carbon dioxide, methane and nitrous oxide. Soil organic matter and plant biomass act as sink for carbon. Additionally, soil bacteria also contribute to this aspect by oxidation of methane. The capacity of soil to capture more CO_2 and decrease in GHGs emission can be achieved by promoting capacity of soil bacteria for oxidation of methane and capture more atmospheric CO_2 (Sarfraz et al. 2019). Recently, the researchers have growing interest in biochar due to its various applications. Biochar is a carbon-rich solid product produced by thermochemical degradation of biomass under a limited presence or total absence of oxygen (Roberts 2016; Arif et al. 2020). The most significant ecological role of biochar is to act as a carbon sink for long term to mitigate climate change (Bird et al. 2017). Moreover, biochar also reduced the emission of green house gases like methane and nitrous oxide. The application of biochar also increased crop yield by improving soil productivity leading to increased biomass and ultimately carbon storage. The characteristics and yield of biochar got affected by pyrolysis condition and type source of biomass used as feedstock. The different raw materials used as feedstock include agricultural residues, sugarcane baggase, sewage sludge, wood and bamboo (Tomozyk et al. 2020). There are some limitations associated with different feedstock as management of agricultural residues on large scale, deforestation due to use of wood and contamination due to use of sewage sludge.

Bamboo is a species of many natural forest and agricultural ecosystem that provides a number of critical ecosystem services. It provides raw material for many services and food, medicine, therapeutic and nutrition in different developing and developed countries (Chongtham and Bisht 2020; Indira et al. 2023; Nikita et al. 2023; Joshi et al. 2023). Some of the ecological applications include regulation of water flow, act as wind breaks in shelterbelts, reduced water erosion along riversides and slopes, offer protection against storms and heavy metal remediation (Emamverdian et al. 2020; Lathwal et al. 2023a; Rani et al. 2023). According to Yiping et al. (2010), the carbon density of bamboo forests ranging from 168.647 to 259.091 t C ha^{-1} which indicates the high carbon sequestration capacity of bamboo. Moso bamboo forest is able to sequester 24-31 t CO_2 ha^{-1} yr^{-1} which is twice of the amount of carbon sequestered by Chinese fir (11.48 t CO_2 ha^{-1} yr^{-1}) and about four times of the amount sequestered by the Massor pine (6.49 t CO_2 ha^{-1} yr^{-1}) (Dwivedi et al. 2019; Xu et al. 2020). Bamboo being a perennial grass and having fast growth rate and high biomass production can be a sustainable source for feedstock for the production of biochar. The properties like high growth rate, high biomass production, easily adaptable to different environment and carbon sequestration gives bamboo an edge over other feedstock sources. Biochar can reduce the GHGs emission and withdrawal of CO_2 from the atmosphere by reduction of carbon mineralization and non CO_2 emission (Agegnehu et al. 2016). The present review will explore the bamboo biomass as biochar feedstock and its properties and contribution to climate change mitigation by means of carbon storage, mitigation of GHGs emission. We will also discuss the current challenges and prospects of future research related to biochar role in climate change mitigation.

The lignin-rich biomass produces higher biomass yield and such observation are allocated to stability of lignin at higher temperature with regards to cellulose and hemicelluloses (Sun et al. 2021). Bamboo has lignocellulosic rich biomass that makes it a suitable feedstock for biochar production. Sahoo et al. (2021) concluded that bamboo has yield more biochar than pigeon pea stalks due to low volatile matter and more lignin content in bamboo biomass. Bamboo biochar is highly carbonized has having low atomic ratio. Many bamboo species such as *Dendrocalamus latiflorus* Munro, *D. giganteus*, *Phyllostachys virdiglaucesons* and dry bamboo stalks are used as feedstock for the production of biochar (Ji et al. 2022). The conditions such as temperature, heating rate and residence time during pyrolization specify the properties and applications of biochar.

2. Bamboo Biochar Properties

Biochar is produced by thermochemical degradation of organic biomass by the process of pyrolyzation that produces syngas and biofuels as well besides the biochar. As CO_2 adsorption and sequestration is correlated with surface area and porosity of biochar, the knowledge about biochar properties is utmost important. The micropore volume plays a crucial role in adsorption capacity as the direct carbon capture occurred at pressure and room temperature. The presence of acidic functional group on the surface resulted due to the thermodegradation of lignin and cellulose at pyrolysis temperature of 400-500^{0}C (Lehmann and Joseph 2015). FTIR analysis of bamboo derived biochar indicated the presence of functional group like ester or ether, C-O-C, CH_4, C=C, benzene ring skeleton and aromatic (Lathwal et al. 2023b). Over the past decade, biochar is extensively studied for the use as an amendment to reduce GHGs emission and removal of atmospheric CO_2 and stored in a stable form in soil (Wu et al. 2019). Bamboo is a lignin rich biomass that produces biochar with high carbon content. Besides carbon, biochar contains elements like hydrogen, nitrogen, oxygen and low content of sulfur. Sahoo et al. (2021) reported that bamboo biochar has high pore volume (0.057-0.18 cm^3 g^{-1}) in comparison of pigeon pea biochar. The process of pyrolization increased the fixed carbon content. In case of bamboo, the fixed carbon content increased by 81.85 to 85.16% in biochar than bamboo biomass (Sahoo et al. 2021). The surface area of bamboo biochar was 123.614 m^2 g^{-1} with pore volume of 0.023 cc $g^{-1}$and pore diameter of 3.363 nm that makes it suitable for adsorb carbon dioxide and other GHGs (Lathwal et al. 2023b). Bamboo biochar is low ash content that makes it less susceptible to with blown and more suitable for transportation and application in soil at far places.

3. Bamboo Biochar Applications

Unique characteristics of biochar make it a suitable material for various applications (Fig.1). Due to its large surface area, high porosity and existence of utilitarian bunches, biochar can adsorb aromatic compounds and heavy metals from the water and soil (Chacon et al. 2020). According to the literature, black carbon affects the microbial community and soil biochemistry which increase the crop yield by improving soil quality (Yadav et al. 2019; Lathwal et al. 2023a). Recent population and economical growth increase the demand for food and change food habits that leads to pile up the waste. Some researches proposed biochar as solution to manage this problem. Biochar stimulates the microbial activity by increasing aeration, reducing gas emission which speeds up the process of composting (Sanchez- Monedero et al. 2018). Biochar increases the crop yield by controlling plant pathogen (Poveda et al. 2021). Due to higher electrical conductivity, biochar can be used in batteries and supercapacitors and possibly in synthesizing cell electrodes, carbon fuel cell and microbial fuel cell (Chacon et al. 2020).

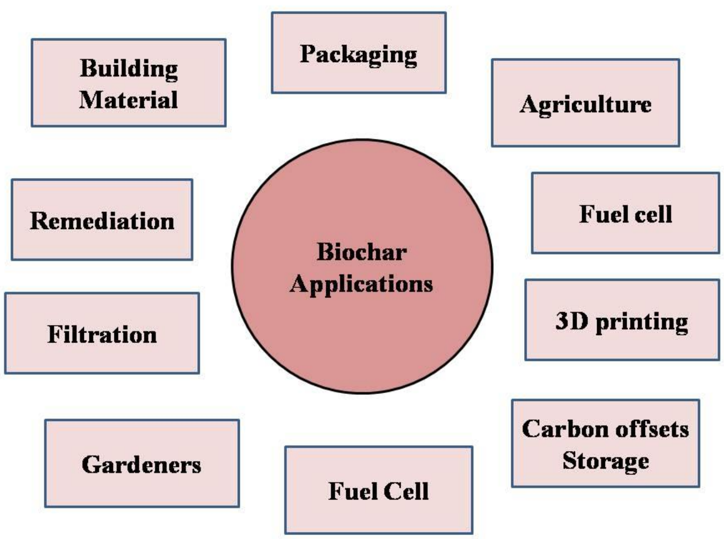

Fig. 1. Different applications of biochar

4. Bamboo Biochar and Soil Health

It is necessary to assess the material suitability before starting any climate change mitigation program. Biochar being an organic material, used as an amendment aimed at improving soil health and fertility. The idea is derived from 'Terra Preta' soil that is known to have characteristics like biochar amended soil. The 'Terra Preta' soils are comparatively more productive and maintain it for a long time (Bezerra et al. 2019). The typical characteristics of biochar like high porosity and large surface area and low density increase the porosity, aggregate stability and porosity of soil while decreasing the bulk density (Yadav 2021). Recent studies have revealed that biochar application increase the water holding capacity and moisture content in forest soil and the application of 20 t ha^{-1} rice straw biochar decreased the average runoff by 28% over a period of 2 years (Li et al. 2017). Biochar is an alkaline material that contains various elements and highly aromatic carbon structures and functional groups like C-O-C on its surface that provide the surface for adsorption of CO_2 and other pollutants. The structure and chemical composition of biochar significantly improve the cation exchange capacity of soil (Mao et al. 2012; Lathwal et al. 2023a). Biochar improves the nutrient availability to the plants by improving the soil health and structure. Biochar improves the concentration of available potassium and phosphorous through adsorption on its large and highly porous surface ultimately. Moreover, bamboo biochar improves the soil fertility and plant yield by stabilizing the pollutant in soil and mitigate their harmful effects on plants.

5. GHGs emission reduction

Different agencies concerned with environment have recognized that climate change is associated with GHG emission to a large extant and to mitigate the climate change the reduction in GHGs emission is necessary globally. According to Paris agreement and the Kyoto protocol, CO_2, nitrous oxide, perflourocarbons (PFCs), methane, sulfur hexafluoride (SF_6) and hydrocarbons (HFCs) are listed as GHGs that needed to be mitigated (Bo et al. 2016). The properties, potency and abundance decide the contribution of these gases in global warming.

Biochar is gaining popularity among the researchers and policy makers due to its potential of green house gases mitigation and magnificent soil amendment (Yadav et al. 2019; Song et al. 2020; Zhang et al. 2023). Recalcitrant and resistant nature of biochar against fast mineralization makes it a favorable amendment over other organic amendments. The mechanism of GHGs emission mitigation is still debatable as there is not clear understanding of pathway of biochar for mitigation. The possible reason could be degradation of forestry and agricultural waste in biochar that may minimize CO_2 and methane emission. The three primary pathways are proposed by the researchers are (i) conversion of biomass carbon into recalcitrant carbon (ii) increase crop productivity by increasing soil quality (iii) direct reduction of GHGs from soil (Fidel et al. 2019). Woolf et al. (2010) reported 12 % year^{-1} reduction in GHGs is possible with application of biochar when used as an amendment in soil. The emission of CH_4 and N_2O reduced from 0 to 1.6 t CO_2e ton^{-1} of biomass with the use of sustainably sourced feedstock (regrown or waste) (Tisserant et al., 2019). The CH_4 emission can be reduced up to 3.9 t CO_2 ton^{-1} of biomass with the application of biochar instead of unpyrolyzed biomass in a flooded paddy field (Matustik et al., 2020). Tan et al. (2018) proposed a biochar-based carbon management plan and a pinch analysis- based approach. By replacing certain fertilizers, biochar reduces the emission of nitrous oxide. The use of residual biomass proposed a solution for waste biomass residue management and decrease in air pollution issues. The reduction in GHGs emission is influenced by biochar type, environment and soil conditions (Borchard et al. 2019).

6. Methane Emission Mitigation

Methane has 28 times more global warming potential than carbon dioxide with a unit mass at 100-year scale (IPCC 2013; Wang et al. 2013). According to NOAA, in 2022, methane in atmosphere increase by 14.0 ppb which is more than two and a half times of their pre-industrialization existence level which leads to 20-30% increase in global warming (NOAA 2022). The natural sources are responsible for around 40% methane emission while remaining 60% is originated from human activity. The largest anthropogenic source of methane emission is agriculture having 25% share followed by energy sector which includes coal, natural gas, oil and biofuels (IEA 2021). Therefore, it can be concluded that the methane contribution in climate change is increased in comparison of CO_2. Several studies suggest that biochar amendment may mitigate the CH_4 emission from soil. Liu et al. (2011) studied the effect of bamboo biochar and rice straw biochar amendment on methane CH_4 emission mitigation and the results showed that both biochars significantly reduced the CH_4 emission during incubation by decreasing the methanogenic activity. Moreover, Han et al. (2016) also indicated the decreasing methanogenic activity and dissolved organic carbon content of soil in paddy soil. The biochar application adsorbs CH_4 and 80% of it was consumed by methanotrophs by diffusion (Conrad and Rothfuss 1991). In another experiment, Wu et al. (2019) observed that CH_4 emission was reduced by 11.2% and 17.5% with the application of biochar at the rate of 20 and 40 t ha^{-1} in an experiment of 6 years.

7. Nitrous oxide Emission Mitigation

The potential of biochar is not fully explored for mitigate the nitrous oxide (N_2O) emission that is restricted by insufficiency of understanding on the mechanism of altering N_2O emission from biochar amended soil. Many researchers reported that biochar application significantly decreased the N_2O emission. The properties of biochar like pH, functional groups present on surface, porosity, specific surface area and redox properties influence the mitigation of N_2O emission (Cayuela et al. 2014). Wang et al. (2011) found that biochar application decreased N_2O emission in paddy soils. A meta-analysis has demonstrated that biochar reduced N_2O emission from soil by 54% in laboratory and field conditions (Borchard et al. 2019). Furthermore, Xu et al. (2020) reported that the application of biochar decreased the concentration of NH_4^+-N concentrations in Moso bamboo forests. The decreased emission of N_2O in soil by biochar attributed to the loose structure of biochar grains that is responsible for adsorbing more NH_4^+-N and NO_3-N (Song et al. 2020). Furthermore, the activity of denitrification microorganisms inhibited by increased oxygen concentration increased by biochar application (Wu et al. 2019). Biochar arrests the loss of nitrogen by reducing the nitrification and denitrification processes with increasing soil CH_4 uptake (Gupta et al. 2020).

8. Carbon sequestration Potential

In 2020, the average global atmospheric CO_2 thrust out a mark of 412 ppm. Due to a surge in CO_2 level in atmosphere, the global temperature is also escalating. The immediate measures are required to limit CO_2 emission, otherwise it is estimate that the global atmospheric CO_2 concentration will reach to the startling level of 600-1500 ppm by 2030 (Li et al. 2023). To mitigate this problem, carbon capture and storage is proposed as a feasible and favorable pathway. Carbon sequestration is the phenomena of trapping CO_2 from atmosphere and storing it in soil in stable forms (Layek 2022). As a climate change mitigation approach, carbon sequestration is a straightforward and potent strategy to trace the carbon accounting. Moreover, carbon sequestration expedites recalcitrant C pool of soil and lower the atmospheric CO_2 level by converting carbon stored in biomass into stable form of carbon (Babu et al. 2020). Thus, biochar production by using biomass and its applications into soil have illustrated a noteworthy potential for carbon sequestration and mitigation of deleterious effects of climate change. One ton of biochar can permanently remove around 2.68 mg CO_2 eq. from atmosphere and sequester around

2.879 mg Co_2 eq. on dry basis (Fawzy et al. 2022). Furthermore, it has been proposed that by 2050, the biochar potential to remove the Carbon will be around 0.3-2 Gt CO_2 y^{-1} (Fawzy et al. 2021). Around 12% of anthropogenic Co_2 emission can be offset by using biochar. Some researches detailed that biochar can stabilize carbon up to 2.27 Pg C y^{-1} (Babu et al. 2023). The biomass has existing fixed carbon which can release in form of GHG so, converting it into biochar makes it stable for a long time. Conversion of biomass into biochar and its applications into soil has been acknowledged as a significant pathway to mitigate the climate change by means of carbon sequestration (Lehmann et al. 2011). The carbon sequestration potential of biochar is about 0.7-1.8 Gt CO_2 eq. y^{-1} (Paustian et al. 2016; Masek et al. 2019). Biochar application into soil changes the carbon cycle from short term geological cycle to long term geological cycle by stabilizing carbon into soil as it has highly stable carbon than other carbon sources (Babu et al. 2023). Moreover, biochar may modify the size and composition of soil microbial community by changing the substrate that substantially affects the sequestration process (Lehmann et al. 2011; Anand et al. 2022). However, the carbon sequestration ability depends on processing conditions and type of biomass used as feedstock. The carbon content increases with the increase in temperature. Biochar produced at 500^0C had higher recalcitrant carbon than biochar produced at 300 and 400^0C (Naeem et al. 2014).

The carbon storage capacity of bamboo forests ranges from 11.6 t C ha^{-1} to 288.5 t C ha^{-1} and around 67-81% was stored within soil which is greater than vegetative layer capacity by 2-4 times (Hou 2020). The carbon sequestration capacity depends on carbon density. Owing to the properties like high biomass yield, carbon sequestration capacity, fast growth and high carbon sequestration potential, bamboo is an ideal raw material for the production of biochar. Bamboo biochar reduces the nitrogen loses in soil when applied as fertilizer with compost. The high adsorption capacity of bamboo biochar is responsible for this positive effect. Adsorption post-combustion is gaining attention due to increasing carbon dioxide emissions. The inexpensive adsorbants are gaining more preference. Overall, biochar application is described as a novel strategy for decreasing the CO_2 emission and an alternate for the adsorption of industrial released gases.

Hernandez-Mena et al. (2014) reported that *D. giganteus* yield 80% biochar at 300^0C because of the high content of carbon. The dry bamboo stalks yield lowest biochar content because of low lignin content. In a study, reported that bamboo biochar has high heating value, higher carbon element and fixed carbon and low ash content than rice husk biochar at the same pyrolyzation temperature. The data reveals that moso bamboo biochar is more efficient for carbon sequestration in comparison of rice husk biochar. The impact of bamboo biochar on crops is studied very well but the impacts on carbon sequestration have gain less consideration (Li et al. 2020). Xu et al. (2020**)** demonstrated that biochar amendment helps in carbon stocks majorly by means of increase in aboveground carbon stocks. The two possible reasons are proposed to explain this increase as first reason was soil porosity and sprouting of Moso bamboo shoots get improved due to porous structure of biochar and secondly, the utilization of deposited Nitrogen in moso bamboo forest soils by biochar that leads to increased growth and biomass. Furthermore, the soil carbon is also increased by biochar amendment. The biochar application increased the SOC of soil and decrease nutrient leaching and activity of carbon-related enzymes and carbon degrading microbes (Song et al. 2020). The negative priming effect might be posed by biochar though trapping labile carbon pool in pores and safeguard of soil C in organo-mineral fractions physically. The CO_2 might bind due to the interaction of clay minerals and functional group available on the surface and reaction with soil particles makes it stable in soil (Zhang et al. 2022). Due to large surface area, clay particles stabilize biochar more than sand particles (Lal et al. 2015). Biochar has higher sequestration rate in carbon starved soil than high carbon contented soil. The rate of soil organic carbon breakdown and presence of carbon in soil is inversely related; thus, biochar improves the soil organic carbon content and reduce the carbon content in soil. Biochar application increases the soil C storage by 2.35 mg C $ha^{-1}y^{-1}$ with the application rate of 4.2 Mg $ha^{-1}y^{-1}$ in sugarcane fields (Canatoy et al. 2022). Zhang et al. (2022) use KOH-activated bamboo biochar for direct air capture of CO_2 and concluded that the activated bamboo biochar is suitable absorber for the CO_2 sequestration. The mechanism of carbon sequestration by amending soil with biochar is not still clearly understood. The previous studies reveal that the mechanism of sequestration majorly relies on soil texture, temperature of pyrolysis and type of feedstocks (Ji et al. 2022). Additionally, the interaction of biochar with environment also influences the time of stability of biochar carbon into soil.

9. Carbon Negative Emission Potential

The oxidation of carbon-intensive fossil fuels directly or indirectly generates carbon dioxide related to the issues of climate change. Presently, the GHGs emission is increasing at a great pace before ever in the history of humankind. The target of limiting the rise by 1.5- 2℃ in global temperature can be achieved by taking three major steps is crucial (1) consideration of different energy management and conservation strategies 2) emphasis on exploitation of different renewable energy sources such as hydro, solar, biomass, wind and geothermal for the replacement of fossil fuels and (3) exploration and implementation of negative emission technologies (NETs) to offset the GHGs emission. NETs include natural processes as well as human efforts to remove the CO_2 from atmosphere (Minx et al. 2018). Carbon capture and storage is considered as promising NETs by government, policy makers and researchers. Some other common NET processes include ocean fertilization, enhanced rock weathering, afforestation and reforestation, bioenergy (biomass) and biochar with carbon capture and storage. Nitrous oxide which is a potent GHG emitted from certain fertilizers, biochar application indirectly decreases the emission of NO_2 (Papageorgiou et al. 2021). Bioenergy with carbon capture and storage is considered as one of the most favorable NETs for mitigating GHGs emission and climate change. The difficulties in handling CO_2 and its leakage due to its harmful effects is a limiting factor for the use of conventional carbon capture and storage system of terrestrial sinks. Opposite to this, biochar can provide a long-lasting carbon sink by everlasting storage in ground as biochar mines and amendments.

Biochar can reduce the GHG emission as well as withdraw the carbon from atmosphere through (i) reduction in non-CO_2 emissions and carbon mineralization in comparison of unpyrolyzed biomass (ii) energy production related to reduce emission associated with fossil fuel and thermochemical conversion related to biomass (iii) increased plant growth with application in soil indirectly increase carbon storage by increasing biomass production and feedstock for biochar production (Azzi et al. 2019; Matustik et al. 2020). The indirect impacts can be caused by change in land use to grow feedstock, biomass management fertilizers need and decreased demand for irrigation (Philips et al. 2020; Papageorgiou et al. 2021). The four direct ways to remove atmospheric Co_2 from atmosphere are (i) higher persistency of pyrolysed biomass than unpyrolyzed biomass (ii) increment in plant growth (iii) reduction of carbon mineralization of soil organic carbon together with negative priming and (iv) carbon capture and storage of pyrolysis gages and liquids (Lehmann et al. 2021). Biochar can capture and store carbon by different means such as soil surface application, artificial biochar mines and filling of empty and barren mines.

10. Artificial Biochar Mines

Artificial biochar mines are also proposed to store carbon in solid form for a long time in underground spaces like unused mines and barren lands. The risk of carbon returning back to the atmosphere is extremely low due to its high stability. Lee et al. (2010) pointed that the Terra Preta soils at Jagaurina (Brazil) and Acutuba (Amazonia) has the presence of biochar particles confirming the storage of biochar particle as a means of carbon sequestration for thousands of years. Generally, microbes are not able to completely degrade biochar. In a recent study, Campbell et al. (2018) found that the decomposition rate of biochar after 200 years is at least 10 times slower that the original biomass feedstock. Biochar stores the carbon for at least for a century which is sufficient for the motivation to store biochar as artificial mines. Biochar mines can significantly use barren mines in storing the carbon for a long time. The best scenario can be identifying a barren land, a plant species with high tolerance potential and biomass production and empty mines for biochar storage. Biochar can be extracted for various purposes from time to time without any costing like other mines. These biochar mines may be a source of energy for a longer time. In addition to, the other benefits of biochar mines include positive energy output with negative emission, low risk, residual biomass management, easy site selection, residual biomass management and economical and environmental sustainability (Thengane and Bandyopadhyay 2020). The sites can be used to grow high value crops and organic agriculture or biochar can be extracted for some other applications like soil amendment, making activated carbon and carbon black. Thus, bamboo biochar production along with storage as biochar mines can be a beneficial negative emission technology.

11. Research Needs and Future Prospects

Biochar plays a promising role to mitigate major climate related changes. It absorbs CO_2 from atmosphere and store in soil acting as a carbon sink. Recently, many studies had studied the role of biochar in carbon sequestration and GHGs mitigation. To achieve the carbon neutral by 2060, there is a need to explore the effectiveness of biochar for climate change mitigation for a prolong time (Li et al. 2023). As applications of biochar predominantly hinge on its properties that are assign by conditions of thermal degradation. Therefore, the future research should be carried out which will be focused on biochar production and influence on its properties. The previous studies clearly pointed that the interaction between soil plant and biochar is crucial for biochar potential. Many developing countries could get benefit by investing in technologies employed for the biochar production at small and large scale varying from small cooking stoves to larger pyrolization systems (Li et al. 2023). Several studies have found that the residence time of biochar is more than 1000 years that makes it a suitable material for carbon capture and storage. Further studies are required to design the long-term behavior of biochar in soil (Yiping et al., 2010). The specification of biochar credited to carbon sequestration and GHGs mitigation will help to develop novel biochar material feedstock and strategy management for enhancing long-term climate change mitigation. The application of biochar to sequester carbon successfully requires the extensive knowledge, technology transfer and capacity building for various stakeholders. Moreover, there is a need to educate policymakers, land managers and farmers about the benefits, limitations and practices for best results (Guo et al. 2016). The comprehensive knowledge about biochar production, properties, applications and potential socioeconomic and environmental impacts should be put forward to policymakers to regulate policy development and implementation. By integrating these perspectives, the knowledge and understanding about biochar use and prevail over the limitations and implementation of biochar for C sequestration and climate change mitigation.

Conclusion

Biochar has proved as a promising tool for carbon sequestration. The potential of biochar to enhance the soil health and fertility, increase C storage and GHGs mitigation is observable. Also, the use of residue of bamboo from other applications can be used for biochar production. The bamboo biochar applications increase soil carbon stocks and vegetation carbon stocks. It also has high carbon content, large surface area and porous structure that result into effective carbon capture and storage. By sequestering carbon and offset GHGs emission, bamboo biochar helps to mitigate the climate change. Although, the stability and persistence of carbon in soil amended with biochar depends on various factors that shows the potential for long term carbon sequestration potential. The interaction of biochar and soil influenced by type of soil, climatic conditions and biochar properties that draw attention to the need of specific assessments regarding the context. With the implications of capacity building, knowledge dissemination and appropriate policy, bamboo biochar can significantly engage in addressing the climate change by carbon sequestration and sustainable land management.

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Conflict of Interest

The authors declare there is no conflict of interest

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