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BIOCHAR APPLICATION : A PROPITIOUS APPROACH TO CLIMATE SMART AGRICULTURE

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ABSTRACT

The increasing challenges posed by climate change require innovative strategies in agriculture to enhance food productivity while minimizing greenhouse gas (GHG) emissions. Climate-smart agriculture (CSA) is an important strategy that addresses the dual challenges of climate change and food security. Application of biochar as soil amendment in crop lands, has been recognised as an efficient and important approach of CSA. Biochar, a carbon-rich material produced from variety of feedstocks through pyrolysis, has high potential of soil carbon sequestration which in turn help not only in improving fertility and productivity of soil, but also in combating climate change. The effectiveness of biochar as a soil amendment mainly depends on the quantity and quality of the biochar which in turn is regulated by the elemental composition, pH, functional groups, and electrical conductivity of biochar. Biochar has certain limitations when used alone which may be overcome by the co-application of biochar with inorganic nitrogen fertilizers. Biochar can also be used as a slow-release fertilizer which may aid in synchronising nutrient supply with plant demand. Thus, judicious use of biochar either alone or in combination of chemical fertilizer can help in achieving food security and also mitigation of climate change.

***Keywords* :** Biochar, Climate change, Climate-smart agriculture, soil amendment, soil fertility.

Introduction

Agriculture under changing climate scenario is facing major challenges of increasing food productivity while reducing greenhouse gas (GHG) emissions caused by various agricultural practices. Conventional agricultural practices involving use of various farm chemicals, in form of chemical fertilizers and pesticides, irrigation and tillage are widely used to increase crop yield and plant protection however injudicious use of these practices results in negative impacts on native vegetation, degrade soil fertility and increase in GHG emission from soil leading to global climate change (Bhattacharyya *et al.*, 2024). Climate-smart agriculture (CSA) is one such strategy that addresses the dual challenges of climate change and food security by sustainably increasing food production, enhancing soil and crop resilience, and reducing greenhouse gas emissions. CSA is also aimed to achieve its three objectives which are popularly known as three pillars viz. adaptation, mitigation and food security (Tasnoova and Iwamoto, 2009). Amongst others, one key approach of CSA is the application of biochar as soil amendment in crop lands. Application of biochar has become important as it has ability to improve the potential of carbon sequestration into soil, which in turn not only help in mitigating the impact of climate change but also improving the soil fertility (Bai *et al.*, 2019). Biochar is a carbon-rich material produced through the pyrolysis process, which involves the thermal decomposition of various feedstocks in an oxygen-limited environment (Rady *et al.*, 2016). For conserving soil health, biochar stands out as a crucial and accessible resource.

Biochar application has been reported to improve soil physical and chemical properties by increasing soil aeration, porosity, moisture content, aggregate stability, water retention capacity and reducing bulk density which intern resulted in improved productivity and fertility of soil (Murtaza *et al.,* 2021). Biochar application has also been observed to enhance soil microbial activity, nutrient availability in the soil, and reduce nutrient leaching (Yin *et al.*, 2021). However, it is influenced by several factors such as the quantity and quality of biochar and the specific soil type. Furthermore, the use of biochar is consistent with the wider goals of sustainable development, particularly the sustainable development goal number 1, 2, 3, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15 (Fig.1) (Kumar and Bhattacharya, 2020).

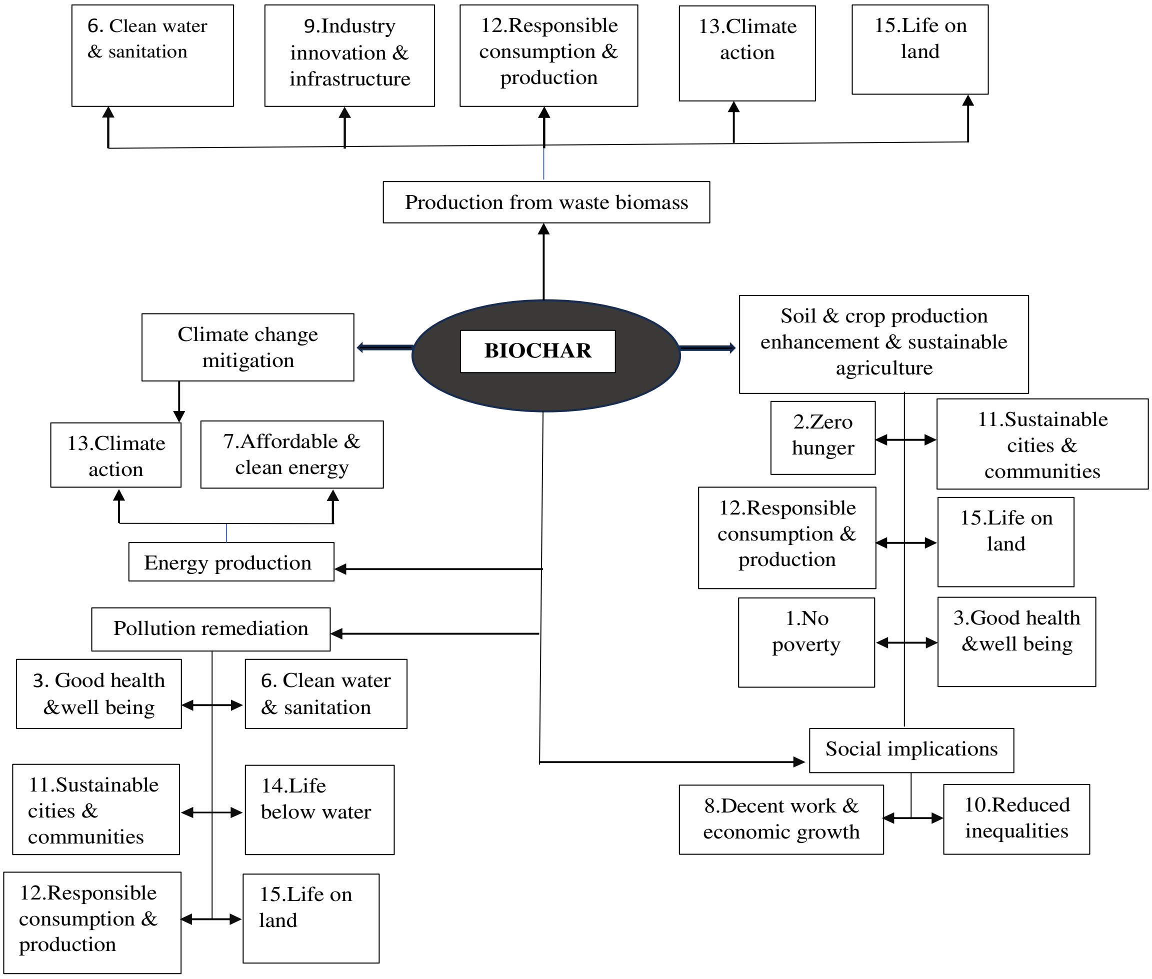

Fig. 1 : Possible achievement of sustainable development goals (SDGs) by production and application of biochar (Adapted from Kumar and Bhattacharya, 2020).

Basic properties of biochar

Elemental composition: The basic structure of biochar is mainly made up of carbon (C), hydrogen (H), oxygen (O), and nitrogen (N) (Kaal *et al.*, 2012). Common metallic elements like iron (Fe) and manganese (Mn) as well as alkali metals like potassium (K), calcium (Ca), sodium (Na), and magnesium (Mg) contribute to its alkaline properties. The source materials and production processes of biochar have an impact on its elemental composition. Compared to sludge and manure-biochar, plant-derived biochar usually has greater carbon content, ranging from 39.75% to 90.21% (Zhao *et al.*, 2022). The dehydration and depolymerization of lignin and cellulose into smaller molecules as the pyrolysis temperature rises is the cause of this increase in carbon content (Xing *et al.*, 2021). Because of its high nutritional content, biochar is an effective soil amendment for improving crop development and restoring nutrient-deficient soils.

pH: Depending on the source, pH of biochar might vary, but it usually rises at higher pyrolysis temperature and involved two major factors as follows:

a. Alkaline and residual inorganic mineral components: SiO_2, $CaCO_3$, KCl, $CaSO_4$, and $-NO_3$. These elements greatly contribute to the pH of biochar being alkaline (Chan and Xu, 2009).

b. Decomposition of acidic functional groups: The high temperatures of pyrolysis during the production of biochar from plant sources encourage the volatilization of organic acids and the breakdown of acidic functional groups such as -COO- and -OH. The acidity of biochar is decreased throughout this procedure, raising the pH. The majority of biochar made from forestry and agricultural waste has a pH between 7.0 to 10.4 (Zhang *et al.*, 2021).

Functional Groups: The unique physical and chemical properties of biochar surfaces, such as their adsorption capabilities, hydrophilic and hydrophobic qualities, and acid-base buffering capacities, are attributed to their richness in different functional groups (Zhang *et al.*, 2021). According to Banik *et al.* (2018), the main oxygen-containing functional groups on biochar are carbonyl, lactone, phenolic hydroxyl, and carboxyl groups. When biochar is produced from different feedstocks at the same pyrolysis temperature, the types and amounts of these oxygen-containing functional groups are generally similar (Zhang *et al.*, 2021). Furthermore, Janu *et al.* (2021) found that key parameters such the temperature of pyrolysis, the specific surface area, the amount of ash, and the H/C ratio had a major impact on the presence of functional groups on biochar.

Electrical Conductance: Biochar exhibits an electrical conductivity (EC) ranging from 0.07 dS m^{-1} to 10.4 ± 0.05dS m^{-1}. The EC of biochar produced from plant wastes and sludge is generally higher than that of biochar formed from manure. The type of raw material utilized and the temperature of pyrolysis have an impact on the EC of biochar. Higher pyrolysis temperatures typically result in biochar with a higher EC as pyrolysis causes the loss of volatile compounds, which raises the residue and ash content (Singh *et al.*, 2017).

Sources and production processes of biochar

Biochar made from ordinary wastes might be a viable solution for environmental sustainability. Common wastes, such as agricultural residues, biomass crops, manures, and sludge wastes, can all be used as feedstock for biochar production (Table 1). Depending on the source of biomass, feed stocks could be classified as herbaceous and woody biomass, human and animal manure, industrial and agro-industrial waste (Lahori *et al.* 2017). The type of feedstocks determines the quality of biochar such as nutrient content, pH, pore structure, sorption rates and ion exchange capacity. Thermochemical conversion is a widely used method for producing biochar involves several technologies, such as pyrolysis, further categorized into slow pyrolysis and fast pyrolysis, gasification (Table 2). These technologies facilitate the production of biochar by utilizing waste materials, thereby addressing energy needs and enhancing soil carbon sequestration. The elemental composition and characteristics of biochar are primarily influenced by factors such as the type of biomass, the conditions under which the reactions occur, and the reactors employed during the carbonization process. Despite being primarily composed of carbon and ash, these variables play a crucial role in determining the final properties of the biochar (Yaashikaa *et al.* 2020).

Biochar as soil amendment

Biochar has become a well-known soil amendment as it has several advantages in agriculture, waste management, and environmental protection (Chen *et al.*, 2022). In comparison to unamended soil, Spokas *et al.* (2009) found that adding biochar in concentrations ranging from 2 to 60% w/w, decreased carbon dioxide emissions, suppressed nitrous oxide production at levels above 20% w/w, and increased ambient methane oxidation.

Recent research highlights the significant potential of biochar in enhancing soil organic carbon (SOC) stocks. Studies indicate that depending on the type of biomass used, application rates, and environmental conditions, biochar can increase SOC levels by as much as 30% or more (Lehmann and Joseph, 2022). Furthermore, certain feedstocks have been shown to produce biochar with enhanced carbon stability, leading to even greater improvements in SOC (Kumar *et al.*, 2023).

Biochar also plays a crucial role as a stabilizing agent for other organic materials in the soil. Its presence helps form complexes with organic compounds, which can reduce the rates at which these materials decompose (Zhou *et al.,* 2023). Long-term field trials have demonstrated that repeated applications of biochar result in cumulative increases in SOC stocks. For instance, a long-term study indicated consistent improvements in SOC levels, particularly in degraded soils (Woolf *et al.,* 2022).

Table 1 : Sources and properties of biochar

Feedstock	Pyrolysis temp. (°C)	Yield (%)	C%	N%	References
Rice straw	300	49.8	74.7	1.72	Wu *et al.* (2012)
	700	34.7	90.6	1.41	
Sewage sludge	300	62.5	39.7	7.1	Agrafoti *et al.* (2013)
Wheat straw	400	34	65.7	1.05	Kloss *et al.* (2012)
Poultry litter	700	36.7	45.9	2.07	Cantrell *et al.* (2012)

Table 2 : Thermochemical conversion processes and production parameters of biochar

Standard methodologies	Operating conditions	Residence time	Biochar yield (approx.)	References
Pyrolysis Slow pyrolysis Fast pyrolysis Flash pyrolysis	300–700 °C 550–1250 °C 800–1300 °C	>450 s 0.5–20 s <0.5 s	Up to 35% Up to 20% Up to 12%	Zhang *et al.* 2021
Gasification	>700 °C	10-20 s	Up to 10%	Yaashikaa *et al.* 2020
Flash carbonization	300–600 °C	<30 min	Up to 40-50%	Zhang *et al.* 2021
Torrefaction	200–300 °C	10-60 min	Up to 80%	Cahyanti *et al.* 2020

Biochar application, however has some limitations. The exclusive application of biochar to soil may negatively impact plant growth by adsorbing mineral nitrogen and readily available organic carbon on its surface. Studies also reported that lower crop yields associated with the sole use of biochar, particularly in soils with a limited supply of available nitrogen (Reibe *et al.*, 2015). Therefore, relying solely on biochar for soil amendment might not be advantageous for intensive crop production. On the other hand, the nitrogen limitation caused by biochar for crops and the subsequent N immobilization can be mitigated through the combined application of biochar with inorganic N fertilizers. The co-application of biochar with urea can help reduce nitrogen losses, thereby increasing nitrogen availability in agricultural soils for an extended period (Sui *et al.*, 2016).

Biochar as slow-release fertilizers

Slow-release fertilizers (SRF) are being deliberately developed to counteract the shortcomings of traditional fertilizers and have gained increasing interest worldwide. Fertilizers that delay nutrient availability for plant uptake are known as SRFs. SRFs release nutrients more slowly than traditional fertilizers, increasing plant availability and decreasing environmental nutrient loss. One of the best methods for lowering nitrogen loss and raising nitrogen usage efficiency (NUE) is the use of biochar-based nitrogen fertilizers (BBNFs) (Dong *et al.*, 2020). For instance, Jia *et al.* (2021) demonstrated a roughly 20% increase in NUE with BBNFs compared to urea.

Slow-release (BBNF) formulations are designed to better synchronize the nitrogen supply in soil with plant demand (Jia *et al.*, 2021). This helps to avoid the large mineral nitrogen pools that can follow the application of mineral fertilizers, thereby reducing nitrogen loss pathways such as denitrification (Puga *et al.*, 2020), leaching and volatilization (Shi *et al.*, 2020). Urea is the most commonly used nitrogen source for producing BBNFs. Urea requires hydrolysis via the urease enzyme in the soil to become plant-available (Shi *et al.*, 2020). Shi *et al.* (2020) demonstrated that, compared to urea fertilizer, the dissolved organic carbon concentration with BBNF remained stable for over 10 days, indicating an interaction between organic matter and mineral additives in BBNFs that protects urea from rapid hydrolysis. González *et al.* (2015) also found that using polymeric coating materials on urea can retard its hydrolysis, resulting in slower nitrogen release. Additionally, Wen *et al.* (2017) noted that hydrogen bonding and electrostatic interactions govern the slow release of ammonium (NH_4^+) in BBNFs. Biochar produced at pyrolysis temperatures between 200 and 400°C, incomplete carbonization leads to more oxygen functional groups, providing sorption sites for NH_4^+ and contributing to slower nitrogen release (Cai *et al.*, 2016). BBNFs can reduce nitrogen losses compared to conventional chemical fertilizers, offering significant environmental benefits (Puga *et al.*, 2020).

Conclusion

The challenge of depleting agricultural land due to the increasing pressure from a growing population has underscored the importance of adopting sustainable crop production practices. Use of biochar has been recognised as an approach important and efficient of climate smart agriculture to enhance soil fertility and productivity thereby achieving food security and mitigation of climate change. However, it has some limitations when applied alone. Co-application of biochar with urea in appropriate combination can facilitate the slow release of nitrogen and reduce nitrogen losses. The effectiveness of biochar depend on its quality and quantity, thus judicious use of biochar either alone or in combination of chemical fertilizer can help in achievement of food security and also mitigation of climate change.

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