Role of Biochar in Sustainable Agriculture: An Overview

Abstract:

Sustainable agriculture is essential for addressing the global food security challenges ~~of food security~~, environmental degradation, and climate change. Biochar, a carbon-rich material produced through the pyrolysis~~ of organic matter~~, has gained significant attention as a promising tool to enhance ~~the~~ sustainability of agricultural systems. Biochar serves as a valuable soil amendment by improving soil structure and enhancing its water-holding capacity, nutrient retention, and microbial activity. These improvements translate into increased soil fertility and reduced nutrient runoff, mitigating the risk of water pollution. Furthermore, biochar's porous structure acts as a reservoir for beneficial microorganisms and can potentially contribute to the suppression of soil-borne pathogens. In the context of climate change, biochar plays a dual role. Firstly, it acts as a carbon sink, sequestering carbon in the soil for hundreds to thousands of years, thus mitigating greenhouse gas emissions. Secondly, biochar application can lead to reduced emissions of nitrous oxide, a potent greenhouse gas associated with synthetic fertilizer use. Crop productivity and yield stability are critical factors in sustainable agriculture. Biochar application has been shown to enhance plant growth by improving nutrient availability, root development, and stress tolerance. Additionally, it can increase crop resilience to extreme weather events, helping farmers adapt to changing climatic conditions. However, the successful integration of biochar into agricultural systems requires careful consideration of feedstock selection, pyrolysis processes, and application methods, as well as site-specific factors. Nonetheless, continued research, development, and knowledge dissemination are essential to maximize ~~the~~ positive impacts of biochar in diverse agricultural contexts.

Keywords: Biochar; sustainability; soil fertility; C sequestration; productivity

1. Introduction:

The world's population ~~is growing every day, which~~ is ever increasing ~~poses a growing~~posing challenges to the global agricultural system. In order to feed the expanding population and meet the steadily rising demand for grains and food, the farming system ~~has~~ need to be~~become~~ more dependent on technology and chemical inputs (Mueller *et al.*, 2012). In order to increase crop yields, agricultural soil has seen an increase in the amount of fertilizer and pesticide application (Pan *et al.*, 2017). During prolonged application, leaching losses of pesticides and fertilizers may occur, reducing soil fertility and polluting the environment. In addition to reducing soil fertility and increasing farming costs, nutrient loss from agricultural soils can also increase soil acidification and reduce crop yields (Laird et al., 2010). In lieu of commercially prepared items, the idea on ~~on~~ natural residue and organic substances has focused the attention of the scientific community and farmers (Ilvo et al., 2019). One of the results of scientific research is biochar, which is crucial for establishing sustainable agriculture and the environment (Lu et al., 2020).

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An effective way to sequester carbon to combat climate change and global warming is through the use of biochar. When incorporated into the soil, it is extremely long-lasting and can persist there for hundreds to thousands of years (Ayaz *et al.*, 2021). Additionally, it is being investigated for environmental rehabilitation, reducing pollutant mobility in polluted soils, and lessening the change of dangerous elements to agronomic crops (Jalal *et al.*, 2020).

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The physical, chemical, and biological qualities of the soil are enhanced by the addition of biochar, which increases the amount of organic matter in the soil. In order to change the agricultural environment, biochar can either positively or negatively impact the microbial growth in the soil (Kavitha *et al.*, 2018).

The Terra Preta, commonly referred to as "Indian black earth," was the first instance of biochar ~~being used~~use to improve soil. Western Amazonia is where the type of soil known as "Terra Preta" was first found. Its black hue, high aggregate stability due to the presence of more carbon, and high nutritional content linked to an increase in microbial presence make it easy to identify (Glaser *et al.*, 2012). The Terra Preta has been discovered to have higher levels of nutrients as well as superior soil rigidity and structure, which results in a more secure organization of soil particles (Alling *et al.*, 2014). Flakes from several varieties of mica were found in the soil sub-layers after Lima et al. assessed the Terra Preta's numerous qualities (Lima *et al.*, 2002). There are several types of acido-bacteria, and the Terra Preta has a 25% greater diversity of bacterial species than other soils (Kim *et al.*, 2007).

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2. Biochar and Its Characteristics:

According to Tan et al. (2015, 2016), biochar is a carbon-rich solid produced by heating biomass with minimal to no oxygen. It has a functional group, a porous carbonaceous structure, and an aromatic surface. The major processes for producing biochar are slow pyrolysis, hydrothermal carbonization, flash carbonization, and gasification (Tan et al., 2015). Biochar is typically made from waste residues including animal manures, agricultural wastes, and forestry wastes. These feedstocks are important because they have the ability to turn waste into biochar, which is a useful and valuable product (Brewer *et al.*, 2014). The usual pyrolysis temperature is between 200 to 800°C (Hossain *et al.*, 2011; Song *et al.*, 2012). At 300℃, *Lantana camara* was used to make biochar that was high in accessible P (0.64 mg/kg), Ca (5880 mg/kg), Mg (1010 mg/kg), and Na (1145 mg/kg) (Antonangelo *et al.*, 2019). A large amount of N ranging from 23 to 635 mg/kg and P ranging from 46 to 1664 mg/kg can be released from freshly made biochar, which is a rich source of readily available nutrients (Jiang *et al.*, 2019). After a day, biochar made from mallee wood was easily drainable with double-distilled water (15-20% Ca, 10-60% P, and 2% N) (Wang *et al.*, 2020). These examples show that biochar may have an impact on soil nutrient levels.

Biochar's adsorption capabilities are influenced by its physical and chemical characteristics. Biochar has extremely high specific surface area, oxygen-containing functional group content, and stability (Huang et al., 2016). The major influences on the physicochemical properties of biochar are the feedstock and pyrolysis temperature (Cantrell et al., 2012).

i. **Surface area-** Biochar's specific surface area is crucial since it aids in the adsorption of chemicals (Inyang *et al*., 2012; Zhao *et al*., 2013). When the pyrolysis temperature was raised from 250 to 600°C, the surface area of sugarcane bagasse biochar raised from 0.56 to 14.1 m^2/g (Ding et al., 2014). The release of volatiles from the biochar increases with the rise in pyrolysis temperature, which could be one explanation (Liu *et al*., 2014). Additionally, the feedstock used affects the biochar's surface area (Lee *et al*., 2013). The biochar's specific surface area and pore structure can be improved by increasing the creation of vascular bundle structures as a result of the release of volatile matter, which is mostly created from celluloses and hemicelluloses during pyrolysis (Li *et al*., 2013).

ii. **Surface functional group-** The amount of hydrogen and oxygen, as well as the molar hydrogen to carbon (H/C) ratio, decrease as the pyrolysis temperature rises. High temperatures also significantly boost the removal efficiency of polar functional groups (-

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OH and C-O) (Ahmad *et al*., 2012). As the pyrolysis temperature rises, the molar oxygen to carbon (O/C) ratio declines, resulting in a greater aromatic and lower hydrophilic surface (Chen *et al*., 2008).

iii. **Cation exchange capacity-** Low nutrient loss from soils can be achieved with high biochar CEC (Steiner *et al*., 2008). When the pyrolysis temperature was raised from 200 to 550°C, the CEC of biochar made from cordgrass appeared to grow from 8.1 to 44.5 cmol(p+)/kg and then fall to 32.4 cmol(p+)/kg (Harvey *et al*., 2011). The CEC of the sugarcane bagasse biochar increased from 6.40 cmol(p+)/kg at 250°C to 9.66 cmol(p+)/kg at 500°C before decreasing to 4.19 cmol(p+)/kg at 600°C (Ding *et al*., 2014).

iv. **pH value-** Applying biochar can increase the pH of the soil due to the pH of the material itself and by enhancing the retention of cations in the soil (Novak et al., 2009; Sohi et al., 2010). Because alkali salts are released from the organic matrix of the feedstock as the temperature of the biochar is increased, the pH of the resulting material is higher (Ahmad *et al*., 2012). For instance, the pH level of biochar generated from maize straw increased from 9.37 to 11.32 when the pyrolysis temperature was elevated from 300 to 600°C (Yuan et al., 2011). Due to their tendency to be more alkaline, biochar made from agricultural wastes aids in raising the pH of soils (Joseph *et al.*, 2010). Contrarily, because of the functional groups that animal wastes give, biochars made from materials like chicken litter or cow manure are much more acidic (Solaiman *et al.*, 2015).

v. **Biochar stability-** Increasing pyrolysis temperatures will increase biochar's stability (Rodon *et al*., 2007; Mašek *et al*., 2013). For instance, the stability of sugarcane bagasse biochar was significantly increased by increasing the pyrolysis temperature from 350 to 550°C. Additionally, biochar made from chicken manure had less stability than biochar made from sugarcane (Cross and Sohi, 2013). Biochar created at low temperatures can often be easily degraded, however biochar produced at high temperatures is resistant to degrading.

vi. **Water Holding Capacity-** When biochar and fertilizer were applied together; there was a 14.6% increase in water content, demonstrating the importance of this porosity in increasing soil water capacity (Agegnehu *et al.*, 2017). An average increase in WHC of roughly 18% results from the addition of biochar (Yu *et al*., 2013). 9.52% weight of sunflower husk biochar resulted in a 30% improvement in water retention capacity (Gluba *et al*., 2021).

vii. **Electrical Conductivity-** Biochar's EC can range greatly between 0.04 and 54.2 dSm^{-1} (Rajkovich *et al*., 2012; Smider and Singh, 2014). The reaction of biochar with water, which releases soluble chemicals, is thought to be the cause of the rise in EC (Joseph *et al*., 2021). According to studies, adding biochar causes the electrical conductivity of acidic red colored soil to rise (Pandian *et al*., 2016). Reduced EC in saline soils may result from the physical entrapment of salts inside the pores of biochar (Thomas *et al*., 2013).

The pH of the soil was raised and dissolved organic matter was released when biochar made from cacao shell and rice husk was heated to 600 and 500℃, respectively (Mandal *et al*., 2021). Humic and fulvic acids' carbon content increased when 10% of biochar made from cow and poultry manure was added to a composting mixture (Jain et al., 2018). Corn straw and mushroom trash can be added to charcoal to hasten the biodegradation of polycyclic aromatic hydrocarbons (Ding *et al*., 2016). The richness in organic carbon and alkaline nature of biochar also improve CEC, which increases the capacity to adsorb heavy

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metals (Gul *et al*., 2015). Biochar could increase porosity by 14 to 64% while reducing soil bulk density by 3 to 31%. Due to its macropores and reduced surface area, it demonstrates a promising behavior of water and nutrient holding capacity in sandy soil (Radwan *et al*., 2020). Biochar therefore has multifaceted role in agricultural systems (Fig 1).

3. Effect of biochar on soil microbes:

The kind of soil and crop has an impact on how biochar affects the activity of soil bacteria (Uzoma *et al*., 2021). In comparison to untreated soils, the diversity of the soil bacterial population increased by 25% after biochar amendment (Otsuka *et al*., 2008). The application of rice straw biochar greatly reduced the Actinobacteria and Ascomycota fungal communities (Farrell *et al*., 2013). When combined with PGPR, rice husk biochar applied at a rate of 3.6 g/kg soil was able to considerably boost rice plant output (Singh *et al*., 2016). Phosphorus and nitrogen uptake by maize plants were increased by 61.5% and 23.1%, respectively, by biochar in conjunction with *Lysinibacillus fusiformi* (Rafique *et al*., 2017). Rice plants' susceptibility to root knot nematode (Huang *et al*., 2017) and *Fusarium* chlamydospore infection in tomato plants (Akhter *et al*., 2015) were both significantly reduced by biochar. With the help of defence-related gene expression, the biochar amendment may result in systemic resistance to fungi (Harel *et al*., 2012).

Increased levels of phenol oxidase and ß-glucosidase were seen in mangrove sediments after biochar additions, while levels of peroxidase, N-acetyl-glucosaminidase, and acid phosphatase were decreased (Luo and Gu, 2016). Acid phosphatase (32%), alkaline phosphatase (22.8%), and fluorescein hydrolases (50%) showed the greatest increases in soil enzyme activity when *Eichornia* biochar was applied at a concentration of 20 g/kg soil (Masto *et al*., 2013; Du *et al*., 2014).

88.6% of L-cyfluthrin was degraded within 5 days by *Brevibacterium aureum* DG-12, a novel bacterial strain discovered in active sludge that can breakdown and use cyfluthrin as a growth substrate (Chen *et al*., 2013). α-endosulfan, ß-endosulfan, and endosulfan sulfate were all digested to 94.1%, 84.5%, and 80.1%, respectively by *Achromobacter xylosoxidans* strain C8B. Microbial consortia may be an environmentally benign technique for pesticide breakdown (Singh and Singh, 2011).

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4. Integrating biochar with soil fertility:

The incorporation of biochar improves soil fertility (Table 1) by facilitating the biological cycle of phosphorus and nitrogen (Gul and Whalen, 2016). The nitrogen fixation rose from 50% to 72% with the addition of 90 g/kg of biochar (Rondon *et al*., 2007). It appears that nitrogen, in the form of NH_3, is less likely to leach when using biochar. Applying wheat straw biochar at rates of 0.5% to 1% was sufficient to stop various types of N leaching (Sun *et al*., 2017). It may be simple to increase the organic matter content of soils by using biochar (Laskosky *et al*., 2020). For crops unable to fix their own nitrogen, biochar also increases the amount of nitrogen available for plant absorption (Zheng *et al*., 2013). Biochar improved soil organic matter's physical security by enhancing C storage in macroaggregates of the fine-coarse soil (Zimmerman, 2010). Sandalwood biochars from Eucalyptus saligna improved the mineralization of native organic C, but not in soil with a clayey texture (Jien & Wang, 2013). Biochar works as a retaining agent for P and stops P from sandy soil from leaching or running off (Glaser & Lehr, 2019; Dharmakeerthi *et al*., 2019). Due to the substantial soil nutrient absorption by biochar, it acts as a slow-release fertilizer (Dal *et al*., 2020). If the soil has a coarse texture and little organic matter, biochar is a viable amendment for stabilizing aggregates (Pituello *et al.*, 2018). When forming aggregates and preventing soil deterioration, biochar may operate as a binding agent for organic materials (Verheijen *et al*., 2010). The

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slow oxidation properties of biochar provide the basis for the long-term effects on soil aggregation (Patel et al., 2015). The majority of the time, plants can easily absorb the potassium present in biochar from its original source (Joseph et al., 2010). The number of cyanobacteria associated with nitrogen fixation & saccharibacteria engaged in organic compound breakdown increased due to the usage of biochar-based fertilizers, thereby improving soil fertility (Liao et al., 2020). The result has positive influence in crop yield and production as well (Table 2).

5. Effect of biochar on soil quality:

Na^+ ions reduce the salinity of the soil; biochar binds to the Na^+ ions and prevents the plant from absorbing them (Akhtar *et al.,* 2015). In order to increase the development of maize, the excessive salinity of central Chinese soils was reduced using a mixture of wheat straw biochar and poultry manure (Lashari *et al.,* 2013). The use of maize stalk biochar increased partial factor production and agronomic efficiency for nitrogen in calcareous sandy soils with zucchini plants, but had no discernible impacts on phosphorus (Amin and Eissa, 2017). The amount of ammonia-oxidizing bacteria in acidic soils was decreased by biochar (Wang *et al.*, 2015). In acidic red soils, adding 10 g/kg of rice straw biochar raised the pH, P availability, and Al^{3+} reduced exchangeable (Zhu *et al.,* 2014).

When biochar was added to soil, the impacts of a higher pH, dispersed metal ions that were liberated, and the active groups on mineral surfaces all worked together to catalyse the hydrolysis of pesticides. According to Zhang et al. (2013), biochar generated from pig manure can hydrolyze carbaryl and atrazine at 350 and 700 °C and 59.1% and 90.6%, respectively. Due to the catalytic properties of biochar, pesticide hydrolysis may be enhanced; however, the increased pesticide sorption may impede this improvement. When pig dung biochar produced at 350 °C after 40 days of incubation was applied at a rate of 0.5%, the breakdown efficiency of carbaryl increased from 55.0% to 75.0% in the unsterile soil (Ren et al., 2016). By affecting the sorption and desorption processes, biochar decreased the microbial atrazine mineralization, hence lowering the atrazine's bioavailability (Loganathan *et al*., 2009). In soil that has been altered with biochar, pesticide mobility, volatilization, leaching, and uptake by plants can all be reduced (Chen et al., 2009). The characteristics of biochar, including its level of organic carbon, fragrance, specific surface area, and ash content, have a significant impact on its capacity to bind pesticides (Fang et al., 2014).

Metals in a soil are immobilized by biochar because of its lower particle size. This immobilization is brought on by the biochar's increased surface area, which finally results in less metal absorption by plant tissues (Zhang *et al*., 2013). When applied at 5%, tobacco stalk biochar decreased the uptake of Cd and Zn by 64.2 and 94.9%, respectively (Yang *et al*., 2017). Rice grain methyl mercury content was decreased by applying biochar made from rice straw and heated to 600 °C at concentrations of 1% to 4% by 49-92% (Shu *et al*., 2016). Rice plants took up less As when Mn modified biochar was applied to As-contaminated soil, and the amount of amino acids rose by 9% (Yu *et al*., 2017). Using biochar in conjunction with other chemicals, including limestone, decreased the uptake of Cd in wheat and rice plant straw and grain by more than 80% (Rehman *et al*., 2017). Plant uptake of metals was frequently decreased by applying biochar at depths of 0 to 15 cm (Forjan *et al*., 2017). The amount of chlorpyrifos and fipronil that *Allium tuberosum* absorbed after being exposed to soil with 1% straw chip biochar was reduced by 19 and 48%, respectively (Yang *et al*., 2010). Chinese cabbage plants' uptake of PAHs was reduced when wheat straw biochar was added at a rate of 2% (Peng *et al*., 2017). The absorption of nanoparticles of cerium oxide by zucchini

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crops could also be decreased by applying biochar made from pecan shells at a rate of 5% (Servin *et al*., 2017).

Polar gases, water-soluble metals, and different organic contaminants are normally all absorbed by biochar (Ahmad *et al*., 2014; Tan *et al*., 2015). Generally speaking, biochars with greater aromatic qualities and greater C condensation are more resilient (Lehmann *et al*., 2015). Biochar efficiently binds heavy metal cations from water and immobilizes elements of heavy metal in soil (Guo *et al*., 2010; Ahmad *et al.*, 2014; Tan *et al*., 2015; O'Connor *et al*., 2018). By interacting with the applied biochar and adhering to the pore surfaces, heavy metal ions in the soil may be changed into hydroxides, carbonates, and phosphate precipitates (Fig 2). As a result of this process, the proportion of heavy metals those are water-soluble and bioactive in soil drops, which diminish their potential for uptake and bioaccumulation by soil organisms, including plant roots (Ahmad *et al*., 2014). By exchanging the cations that were previously connected to its surface functional units through ion exchange, biochar is able to adsorb heavy metal ions from the soil solution (Fidel *et al*., 2018). Biochar sorbs Cd, Cu, Ni, and Pb mostly through surface complexation, which makes use of ligand-like surface functional elements like carboxylic, hydroxyl, and phenolic groups (Uchimiya *et al*., 2011). The addition of alkalinity from biochar often results in an increase in soil pH. Increased pH promotes heavy metal hydrolysis, which results in the creation of metal hydroxide precipitates. This lowers the amount of metal ions that is soluble in water and helps minimize soil heavy metal contamination (Ippolito *et al*., 2017). Organic non-ionic compounds are adsorbable on biochar via surface adsorption along with partitioning. Because of their higher surface energy, biochar micropores are where the adsorption of organic pollutants begins (Uchimiya *et al.*, 2011). Metal ions can combine with polar and charged organic molecules to produce complexes that can either be deposited on the surface of the biochar or precipitate in the soil (Tan *et al*., 2015).

6. Effect of biochar on greenhouse gases:

By adding biochar to soil, it is possible to reduce CO_2 emissions by 1.67 tonnes of CO_2 equivalent every tonne of feedstock utilized (Tisserant and Cherubini, 2019). It is important to note that woody biomass-derived biochar delivers greater emission reductions because of its increased energy content, which can counteract GHG emissions created during the biomass burning process (Lehmann *et al*., 2021). It was proposed that biochar might deliver a maximum of 15-35% of the carbon dioxide reduction target by using residue biomass and growing additional crops expressly for biochar production (Tisserant and Cherubini, 2019). Additionally, iron- or calcium-treated biochar demonstrated its value in increasing the stability of soil aggregates and lowering carbon emissions with improved carbon sequestration abilities (Liu *et al*., 2020). Because biochar decomposes organic carbon more slowly than straw biomass, applying it to paddy fields minimizes CH_4 emissions from those areas (Lehmann *et al*., 2021). The addition of biochar leads in less CH_4 being released from the carbonaceous substances than straw biomass and inhibits the spread of methanogenic bacteria by providing a comfortable environment in its porous structure (Jeffery *et al*., 2016; Wu *et al*., 2019).

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Additionally, biochar enhances the production of N_2O reductase genes in denitrifying bacteria and encourages microbial N immobilization (Lehmann *et al*., 2021). This makes it easier for N_2O to be converted to N_2 during denitrification, which lowers emissions of N_2O from soil (Cayuela *et al*., 2013). N_2O emissions dropped by 50% after the addition of wood biochar formed at 350 °C and 700 °C biochar, respectively (Ameloot *et al*., 2013). Utilizing biochar made from pine, willow, and corn, which were all created at 550 °C, decreased N_2O emissions by around 40%, 46%, and 60%, accordingly (Nelissen *et al*., 2014). Higher-

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temperature biochars were more effective at lowering the release of N_2O than NO emissions, and lower-temperature biochars are more effective at lowering NO emissions. Crop yields increased and N_2O emissions decreased after straw-derived biochar was added to sandy-loam soils for a five-year wheat and maize crop rotation, but total GWP did not change (Liu *et al.*, 2020). It is believed that biochar will have the ideal characteristics for preventing global warming and changing the climate (Downie *et al*., 2012). Numerous research support the idea that applying biochar to areas used for cultivating vegetables will significantly reduce emissions of carbon dioxide, N_2O, and methane gasses (Sun *et al*., 2014; Hale *et al*., 2020).

7. Effect of biochar in sustainability:

In order to create new agricultural techniques that are secure and ecologically sound, according to Littfouse et al. (2009), "sustainable agriculture" is the combination of socioeconomic research with biological, chemical, physical, and ecological functions. By conserving and upholding all of its natural resources, such as conserving soil fertility, protecting surface and below-ground assets, creating renewable energy sources, and looking for ways to adapt farming practices to climate change, sustainable agriculture enables agro farming to sustain itself over an extended period of time (Jala *et al*., 2020; Akhtar *et al*., 2020). Agro farming needs to take social groupings and the environment's sustainability into account.

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The main challenges facing the existing agro farming methods are to increase crop yield in a way that is environmentally sound and sustainable (Hamilton *et al*., 2016; Srivastav, 2020). A more sustainable approach to farming will lessen the need for organic fertilizers and maintain the productivity of agriculture. The majority of current biochar research focuses on modifying the material's characteristics to improve its ability to remove both organic as well as inorganic contaminants (De Boer & Kowalchuk, 2001). Biochar exhibits amazing efficacy in decreasing contaminants including antibacterial agents, herbicides, pigments, pesticides, and heavy metals due to its outstanding surface properties, and it is essential in addressing the effects of climate change (Schiermeier, 2006). The extraordinary ability of biochar to immobilize rhizospheric heavy metals and agricultural pesticides on its vast surface and prevent their uptake by crops increases crop production (Bolan *et al*., 2013). It has been demonstrated that adding biochar reduces the soil's maximum hydraulic conductivity, particularly in light-textured soils (Brockhoff *et al*., 2010; Lehmann *et al*., 2003).

8. Limitations of the use of biochar:

There are several restrictions even if the majority of research data demonstrated the advantages of biochar treatments. Additionally, *Oryza sativa* and *Solanum lycopersicum*'s subsurface root biomass decreased in response to aged biochar (Anyanwu *et al*., 2018). It has been demonstrated that biochar has favourable soil-specific impacts (Zhu *et al*., 2015). Using biochar at a high level in lentil cultivation caused the development of weeds to rise by 200% (Safaei Khorram *et al*., 2018). Implementation of biochar may also cause plants to blossom later (Hol *et al*., 2017). In saline sodic soil, applying biochar and phosphorus fertilizer together may speed up the phosphate precipitation/sorption processes. This interaction may ultimately result in the plants' access to phosphorus being reduced (Xu *et al*., 2016). It has been demonstrated that the biochar source's contamination is harmful for crop development (Jones and Quilliam, 2014). Based on the kind, quantity, kind of soil, crop variety, etc. of the biochar amendment, beneficial as well as detrimental impacts on crop production and fertility fluctuations might occur.

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9. Future line of research: use of nano biochar:

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With the development of nanotechnology, studies have been done on the sustainable production of nano-biochar for land and agricultural use. A micro-sized biochar known as "dissolve" and "nano-biochar" is created during the carbonization process. It has dimensions less than or equal to a micrometer and up to a nanometer. Recent research produced nano-biochar with a diameter <5 nm. The structural modifications and physico-chemical properties of bulk biochar and nanobiochar differ from one another. The elemental compositions, aromatic/polar nature, pH, CEC, specific surface area (SSA), pore properties, and Zeta potential of nano-biochar can all vary. Nano-biochar is also available in soluble and insoluble forms. Dairy manure biochar generally has a soluble carbon concentration that ranges from 14% at 100℃-0.2% at 700℃, with the soluble carbon content usually rising according to rising solvent pH and decreasing with rising pyrolysis temperature. As a result of rising instances of environmental degradation and decreased crop productivity caused by shifting climatic circumstances, nano-biochar becomes increasingly intriguing (Chen *et al*., 2015; Liu *et al*., 2018; Rajput *et al*., 2022).

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10. Conclusions:

Last but not least, biochar shines as a ray of hope in our pursuit of sustainable farming, improved soil health, vigorous cultivation, and efficient climate change management. Its many advantages, including increased nutrient retention, less release of greenhouse gases, and greater soil capacity to hold water, offer a positive vision for a more robust and environmentally conscientious agricultural destiny. We can lessen our impact on our surroundings, repair damaged soils, and equip farmers to meet the hurdles of a changing climate by incorporating biochar into our farming practices. With the use of biochar, we may conserve nature without sacrificing crop output by delaying the release of resources. Biochar must be seen as more than just a fix—it must be seen as a road toward a more peaceful living with our planet as we work to fully realize its potential through continued study and creative use. We make a big step towards sustainable farming, better ecosystems, and a more sustainable planet for future generations by embracing biochar.

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Table 1: Nutrient retention by biochar and their effect of feedstock, pyrolysis temperature and application rate

Nutrient	Feedstock	Pyrolysis temperature (℃)	Rate of biochar application	Adsorption capacity (mg/kg)	Reference
NH_4^+	Brazilian pepperwood	300	0.1g 50m/L	190	Yao *et al.*, 2012
		450		785	
		600		595	
	Arundo donax L.	300	0.35g 12m/L	2101.9	Zheng et al., 2013
		350		1432.6	
		400	0.8g 12m/L	1043.4	
		500		362.8	
		600		371.8	
NO_3^-	Brazilian pepperwood	600	0.1g 50m/L	20.6	Yao *et al.*, 2012
	Arundo donax L.	500	0.3g 8m/L	171.8	Zheng et al., 2013
		600		533.5	
PO_4^{3-}	Wheat straw	350-550	1%	333	Xu *et al.*, 2014
			5%	625	
			10%	769	
	Sugarcane bagasse	450	0.1g 50m/L	477.4	Yao *et al.*, 2012
K^+	*Spartina spartinae*	300	A solution flow rate of 0.30–0.35 mL/min; 50–60 mg of biochar	19.5	Harvey et al., 2011
		350		20.3	
		550		12.5	
	Pinus taeda	300	A solution flow rate of 0.30–0.35 mL/min; 50–60 mg of biochar	6.6	Harvey et al., 2011
		350		10.9	
		650		1.2	

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Table 2: Dynamics of biochar and its effects on crop

Sl No	Type of biochar	Temperature	Area of study	Rate of application	Soil type	Effect on crop yield	Reference
1	Wheat Straw	300–500℃	China	3% w/w	Psammaquent and Plinthudult	Rice	Muhammad et al., 2017
2	Rice Straw and Corn Stalk	450℃	China	1, 2& 4 t/ha	Inceptisol	Corn, Peanut Sweet potato	Yang et al., 2015
3	Cow Manure	600℃	Japan	0, 10, 15 and 20 t/ha	Sandy soil	Maize	Azeem et al., 2019
4	Rice Husks	450 ℃	China	0, 10, 25 and 50 t/ha	Upland soil and paddy soil	Rice, Wheat	Wang et al., 2012
5	Maize Stover	600 ℃	USA	0, 1, 3, 12 & 30 t/ha	Kendaia silt loam	NA	Güereña et al., 2012
6	Woodchips	700℃	USA	5% w/w	Clay texture and sandy loam texture	NA	Lai et al., 2013
7	*Eucalyptus polybractea*	550℃	UK	10 t/ha	Ferrosol Soil	Cauliflower, peas, Broccoli- no significant effect	Boersma et al., 2017

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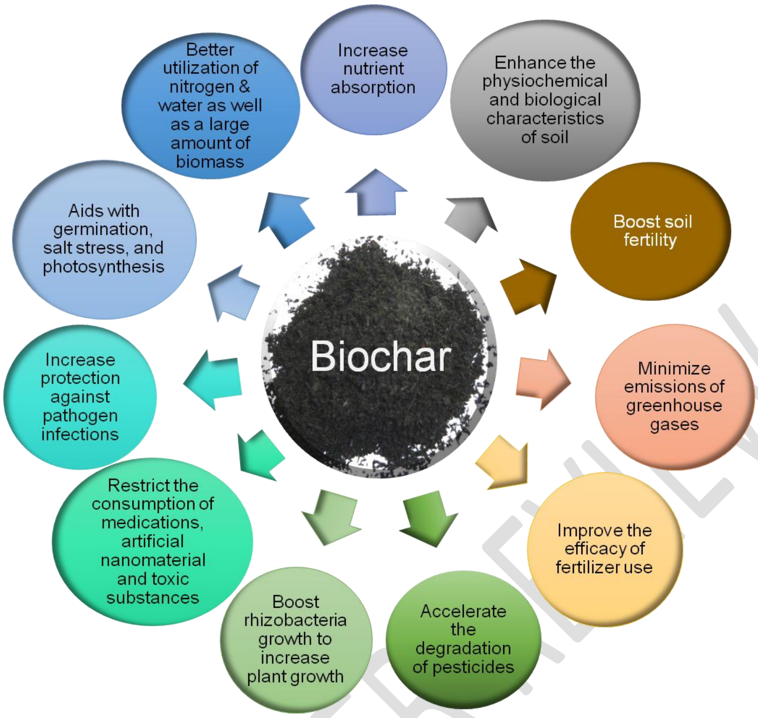

Fig 1. Benefits of the use of biochar in soil-plant systems

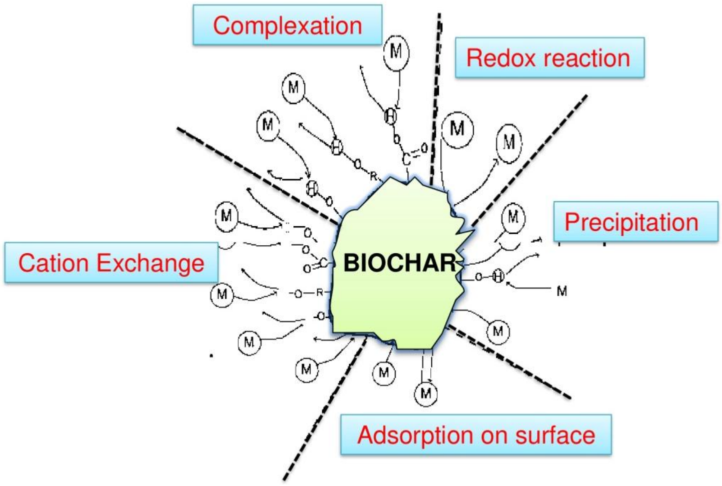

Fig 2. Reaction of biochar in retention of nutrients and heavy metals

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