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9. Biochar Applications in Agriculture

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Abstract:

Biochar, a carbon-rich material produced through the pyrolysis of organic matter, has gained increasing attention for its multifaceted applications in agriculture. Biochar's ability to sequester carbon, improve soil structure, and enhance nutrient retention in soils has made it a valuable tool for mitigating climate change and increasing agricultural productivity. Its porous structure fosters microbial activity, promoting healthier soil ecosystems, and reducing the need for chemical fertilizers. Moreover, biochar can serve as a potent tool in managing soil contaminants and reducing the environmental impact of agricultural runoff. This review also highlights the importance of biochar feedstock selection, production methods, and application techniques to optimize its potential in different agricultural contexts. The versatility of biochar, combined with its sustainable and environmentally-friendly attributes, positions it as a promising solution to address contemporary agricultural challenges while contributing to a more sustainable and resilient food production system.

Keywords:

Biochar, Soil properties, Plant growth promotion, Microbial diversity.

9.1 Introduction:

Biochar, a carbon-rich material produced through the pyrolysis of organic matter, has gained increasing attention for its multifaceted applications in agriculture. This abstract explores the diverse roles and benefits of biochar in enhancing agricultural practices. Biochar's ability to sequester carbon, improve soil structure, and enhance nutrient retention in soils has made it a valuable tool for mitigating climate change and increasing agricultural productivity. Its porous structure fosters microbial activity, promoting healthier soil ecosystems, and reducing the need for chemical fertilizers. Moreover, biochar can serve as a potent tool in managing soil contaminants and reducing the environmental impact of agricultural runoff. This review also highlights the importance of biochar feedstock selection, production methods, and application techniques to optimize its potential in different agricultural contexts.

The versatility of biochar, combined with its sustainable and environmentally-friendly attributes, positions it as a promising solution to address contemporary agricultural challenges while contributing to a more sustainable and resilient food production system.

Biochar is finely ground charcoal with similarities to activated charcoal which offers an extremely high surface area to support microbiota and increase nutrient availability for plants.

Due to high surface area, it can support microbes that reduce nitrogen loss and increase nutrient availability for plants. A strategy to deploy biochar on a large scale to sequester carbon as thermally stabilized biomass using existing organic resource is estimated to be at least 1 Gt yr^{-1} and is expected to provide a benefit from enduring physical and chemical properties (Sohi*et al.*, 2010). Several studies reveal that charcoal tend to suggest stability in the order of 1000 years in the natural environment.

Biochar can influence the global carbon cycle in two main ways.

- Biochar is produced from materials that are otherwise have oxidised, and the resultant carbon-rich char is placed that is protected from oxidation, which sequester carbon that would otherwise have entered the atmosphere as a greenhouse gas.
- The gaseous and liquid products of pyrolysis may be used as a fuel that can counterbalance the use of fossil fuels.

Studies have reported on the beneficial impacts of biochar addition on soil health improvement. The incorporation of biochar into soil alters soil physical properties like soil bulk density, structure, aggregation, soil stability, pore size distribution and density, soil aeration, water infiltration, water holding capacity, soil chemical properties include like retention of nutrients, enhancing cation exchange capacity and nutrient use efficiency, decreases soil acidity, decreases uptake of soil toxins and increases the number of beneficial soil microbes etc.

9.2 Preparation of Biochar:

Based on the requirements biochar units can be planned. For laboratory studies, small units are fabricated. The combustion chamber of the biochar unit is filled with 10 kg chopped pieces of plant species. The temperature is kept around 500°C for 24 hours.

The completion of process can be noted from the flame colour of yellow to blue with little smoke which implies that there is a complete burning of the fuel. At the end of the process all the biomass is turned into char. Biochar material can betaken out, cooled and ground to a size of <0.5mm which was taken for all physical and chemical analysis. It can be planned according to the requirements.

9.3 Characterization of Biochar:

The macroporous structure (>1 μm diameter) of biochar produced from cellulosic plant material inherits the architecture of the feedstock, and is potentially important to water holding and adsorption capacity of soil.Surface area measured by gas adsorption, however, is influenced by micropores (nm scale) that are not relevant to plant roots, microbes, or to the mobile soil solution.

Pyrolysistemperature influences the surface area, carbonized fractions, pH and volatile matter and a decrease of CEC and content of surface functionalgroups (Tomczyk *et al*., 2020). Process temperature is the main factor governing surface area, increasing from 120 $m^2 g^{-1}$ at 400 ºC to 460 $m^2 g^{-1}$ at 900 ºC (Day *et al*., 2005).

The importance of temperature leads to the suggestion that biochar created at low temperature may be suitable for controlling release of fertilizer nutrients (Day *et al*., 2005), while high temperatures would lead to a material analogous to activated carbon (Ogawa *et al*., 2006).It is also noted that the surfaces of low temperature biochar can be hydrophobic, and this may limit the capacity to store water in soil. The form and size of the feedstock and pyrolysis product may affect the quality and potential uses of biochar. Initially, the ratio of exposed to total surface area of biochar will be affected by its particle size. However, although low temperature of biochar is stronger than high temperature products, it is brittle and prone to abrade into fine fractions once incorporated into the mineral soil. Biochar found to have alkaline in reaction with soluble satls, moderate CEC and total nutrients like, nitrogen, phosphorus, potassium and sulphur **(Table 9.1).**

The microscopic analysis confirmed that plants species contain nutrients **(Figure 9.1)** including heavy metals. It varies from plant species. *Eichorniasp*isfound to accumulate heavy metals and hence continuous application of biochar from *Eichorniasp* may lead to accumulation of heavy metals in soil. Plant species like *Prosopissp*can be harnessed effectively. Nature and properties of biochar varies with the sources of biomass prepared (Sellamuthu*et al*., 2018).

Table 9.1: Properties of biochar derived from different plant communities

Biochar	**EC dSm^{-1} (1:5)**	**pH (1:5)**	**CEC (cmol $(p^+) kg^{-1}$**	**Total N (%)**	**Total S (%)**	**Total P (%)**	**Total K (%)**
Lantana	4.07	10.20	18.0	0.923	0.516	0.390	1.797
Dodonia	1.50	9.10	13.8	0.426	0.315	0.100	0.194
Eichornia	7.50	10.38	23.8	1.421	0.671	0.872	3.096
Prosopis	3.03	9.80	18.8	1.02	0.371	0.160	1.226
Melia	2.93	9.94	23.0	0.848	0.314	0.199	1.670
Gliricidia	3.30	10.13	16.0	1.188	0.278	0.048	0.625
Delonix	1.98	8.47	17.5	0.91	0.237	0.511	1.597

(Source: Sellamuthuet *al*., 2018)

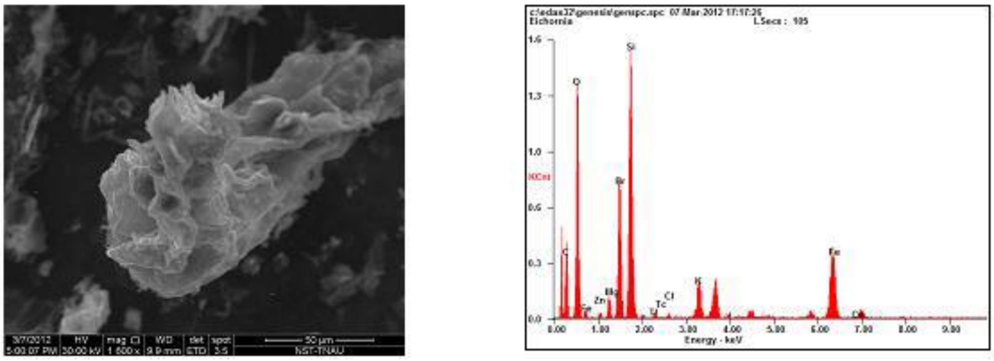

Figure 9.1: Scanning electron microscopic view of biochar from Eichorniasp

9.4 Influence of Biochar on Soil Properties:

Marked impacts of low charcoal additions (0.5 t ha^{-1}) on various crop species, but inhibition at higher rates (Glaser *et al.,* 2001) has been observed. Positive yield effects from biochar addition was reported by Kimetu*et al*. (2008), who were able to establish that the impact were in part due to non-nutrient improvement to soil function.Understanding the link between biochar function and its interactions with nutrients and crop roots may enable fertilizer use efficiency to be improved. Quantitative description for the function of biochar with respect to water infiltration, water retention, macroaggregation, and soil stability would enable prediction of beneficial properties, and selection of biochar with particular properties for use in specific environmental and agricultural contexts.

Since, biochar could be used on a large scale and cannot be removed from soil once applied, there is a need to carefully assess the potentially impacts on health, environmental pollution, water quality, and food safety. This requires concerted effort to evaluate potential products, and ideally define product standards. The lack of mechanistic understanding as to the function of biochar, and its interaction with already complex soil processes does not yet exist. Hence, characterizing different sources of biochar could pave the way for its potential use and its impact on natural ecosystem. Possibly the wastes and obnoxious weeds can also be used as feed stock to prepare biochar.

9.4.1 Effect of Biochar on Soil Physical Properties:

Biochar amendment promotes aggregate formation, increase water movement, increase the saturated water content and decrease the residual water content attributable to soil structure changes. Soil bulk density is one of the most studied properties following biochar application. Research findings indicates that biochar application can reduce bulk density in coarse-textured soils more than in fine-textured soils. It reduces bulk density by 14.2% in coarse-textured soils and 9.2% in fine-textured soils. Biochar has a lower bulk density than soil and hence biochar application probably reduces the density of the bulk soil through the mixing or dilution effect (Blanco Canqui, 2017). Decrease in soil bulk density and particle density with biochar application can affect soil porosity.

Similar to bulk density, biochar appears to increase porosity more in coarse-textured soils than in fine-textured soils.Biochar have a porosity of 70 to 90%. Biochar increases porosity of soil by reducing bulk density increasing soil aggregation, and reducing soil packing. Application of biochar generally reduces soil bulk density by 3 to 31% and increases porosity by 14 to 64%. Application of biochar can retain more water in coarse textured soil and increase hydraulic conductivity in fine textured soils.

9.4.2 Biochar effects on Soil Physico-Chemical Properties:

The pH of biochar is ranging between 4 and 12, and its alkaline property directly affects soil pH after its application. Biochar can regulate the soil pHand increase the base saturation of the soil.Compared to the effects of biochar on acidic soil pH, relatively little research has been conducted on these effects on alkaline soil pH. After adding biochar to acidic soils, the pH value of the soils increases. Addition of biochar to soil can increase the soil CEC levels. However, excessive biochar additions reduce soil productivities and inhibit soil chemical activities (Zhang *et al*., 2021).

9.5 Influence of Biochar on Soil Fertility Properties:

Biochar influences the organic carbon content significantly. Application of biochar prepared from *Eichornia sp.* at 7.5 t ha^{-1} is found to record higher available N and available P during all the stages of crop growth but the effect was significant in early stages of crop growth. Biochar from *Eichornia sp.* @ 10.0 t ha^{-1} wasfound to record higher available K.

Biochar additions increase available phosphorus and available potassium. Available nitrogen was decreased due to the application of biochar that is able to improve the utilization of soil nitrogen by plants. The decline of soil available nitrogen may be caused by the increase in soil pH, which can promote the transformation of ammonium nitrogen into nitrate nitrogen, leading to the reduction of available soil nitrogen (Chen et al. 2013).

9.6 Biochar and Soil Biological Properties:

Application of charcoal stimulates indigenous arbuscular mycorrhiza fungi in soil and thus promotes plant growth. The relationship between mycorrhizal fungi and charcoal may be important in realising the potential of charcoal to improve fertility.

Also it was found to be ineffective at stimulating alfalfa growth when added to sterilised soil, but that alfalfa growth was increased by a factor of 1.7-1.8 when unsterilised soil containing native mycorrhizal fungi was also added. The reason was either alteration of soil physico-chemical properties; indirect effects on mycorrhizae through effects on other soil microbes; plant–fungus signalling interference and detoxification of allelochemicals on biochar; and provision of refugia from fungal grazers (Warnock *et al.*, 2007).

Addition of biochar significantly alters the structural composition of soil microbes. Biochar's surface contains partially soluble carbon sources and N sources that are conducive to microbial activity (Hamer *et al*., 2004).

9.6.1 Biochar as Soil Amendment:

Biochar is considered as an effective soil amendment for reducing soil acidity due to its lime potential. It enhances the soil fertility and productivity in acid soils. Use of lime for the amelioration of soil acidity remains well established. Limited availability and high cost of liming materials in some regions limit its application, thus resulting in large areas of reported soil acidification (Manya *et al.*, 2018).

Liming materials including biochar ameliorate soil acidity through both direct and indirect effects. The direct effect was achieved by enhancing physicochemical and biological soil characteristics and indirectly by mobilizing essential nutrients for plant uptake and immobilizing toxic pollutants.

9.6.2 Biochar on Growth and Yield of Crops:

Studies on yields of crops like wheat, maize, canola, barley, rice, sorghum, tomato, groundnut, faba bean, turnip, and peanuts proved that biochar applications significantly increasedcrop yield compared to the control (Singh *et al*., 2022). Sources of biochar could not influence seed cotton yield and Tomato fruit yield but among the levels of biochar, 5.0 t ha^{-1} exerted a significant influence on the yield (Sellamuthu, 2018)

9.6.3 Greenhouse Gas Mitigation Through Biochar:

The charcoal formation pathway is known for sequestering atmospheric carbon intothe terrestrial reservoir via stabilization of short-term cycling biogenic carbon into long termcarbon pool. The upper 100 cm surface soil of earth contains around 1200-1600 Gt globalorganic carbon pool which has massive sequestration potential as if we consider the global emission of CO_2 carbon from the combustion of fossil fuel which is around 270 Gt since 1850to 2000.

9.7 Conclusion:

Desertification and drought increase globally due to climate change, hence novel and effective solutions are imminent to enhance food production for the world’s burgeoning population. Synthetic fertilizers were used to improve the productivity of agricultural soils for quiet long time and apportion of it leaches into the environment which emits greenhouse gasses (GHG).

Improvement of physical properties of soils for better water retention and drainage, sustaining chemical properties for optimum nutrient availability and utilizing organic as well as biological inputs for making conducive environment for microbiota as well as boosting the efficiency of fertilizers are some fundamental challenges within agricultural practices. Biochar is a nutrient rich material produced from biological materials, gaining attention for different soil purposes including soil amendments, improving crop yields as well as for carbon sequestration. Biochar has a potential role to play in carbon credit systems. Biochar can be effectively utilized for attaining environmental benefits and economic benefits.

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