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Biochar: Magic Black Carbon for Agricultural and Environmental Sustainability

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Abstract

Biochar is a kind of charcoal having very high surface area, produced by the controlled pyrolysis of organic biomass, can be used as soil amendment which improves soil health with increasing crop production. Biochar is produced from combustion of biomass in controlled way under oxygen-free or oxygen-limited environment. The particular heat during pyrolysis converts organic biomass into biochar with large surface area that enable them to persist in soils with very little biological decay, useful in agricultural perspective. Due to high mean residence time, biochar virtually creates permanent carbon sinks which improves soil health substantially in an environmentally sound manner. The biochar (acts as catalyst) improves intake of nutrients along with water in the plant. Owing to have porous structure together with large surface area, the biochar can retain or adsorb water and various soil nutrients and act as a natural terrain for useful soil microbes to grow.

Introduction

Biochar is a relatively new term; however, it is not a new substance. Biochar deposited in soil through natural events, such as forest and grassland fires has been reported throughout the world. Biochar was reported to be present in different part of the world since ancient time. In fact, natural deposit of biochar in the areas like North American Prairie is some of the most fertile soils in the world. There are evidences of use of biochar from 2000 years ago. The concept of 'Terra Preta' which is also known as Amazonian Dark Earth was found to be mentioned in literature (Glaser and Birk, 2012). In the Amazon basin, extensive use of biochar can be observed in unusually fertile soils known as Terra Preta and Terra Mulata, which were created by ancient indigenous cultures. This Terra Preta soil contains up to 70 times more black carbon than surrounding soils (Glaser and Birk, 2012) with high level of nitrogen, phosphorus and sulphur. In parts of Asia, especially in Japan and Korea, have long history of biochar application in agriculture. Recently, growing interest towards sustainable farming systems, such as Korean Natural Farming, has rejuvenated the biochar application in western agriculture.

Production of Biochar

Pyrolysis is the main process involved in production of biochar that largely depends upon the temperature and atmosphere used for charcoal production. The slow pyrolysis process *i.e.*, moderate temperature and O_2 free atmosphere with long residence time is ideal for biochar production. The types of feedstock and operating conditions for biochar production greatly affect its relative quality as a soil amendment. The most important measures of biochar quality are associated with high adsorption and cation exchange capacities (CEC) with low levels of mobile matter (tars, resins). Production of biochar is an endothermic process, heat is required to increase the temperature of the substrate and break the molecular bonds. The oil, volatile mater and gases that are released can be recovered for other uses, including production of electricity (Figure 1). A sustainable model of biochar production primarily uses waste biomass, such as green waste from municipal landscaping, forestry, or agriculture.

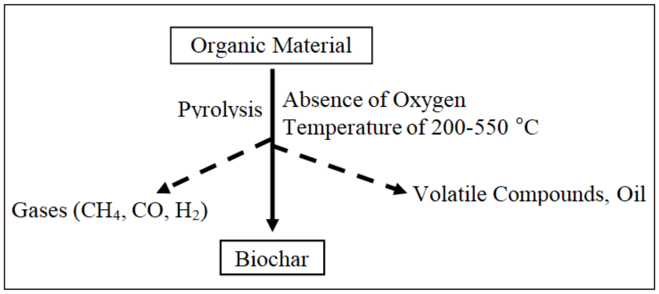

Figure 1: Schematic flow diagram of biochar production technique

Properties of Biochar

Characterization of any substance is the first and foremost step to understand the mechanism of action. Difference in characteristics of black carbon can be observed depending upon different biomass and different timescales used during production. Various physico-chemical properties like particle size, water holding capacity, bulk density, specific surface area, pH, EC, CEC and carbon content are important in respect to its role in improving soil health. The pH of biochar generally ranges from 8.2 to 13.0. Total carbon content varies from 33.0% to 82.4% with low nitrogen content (0.18-2.0%) and C:N ratio varied from 19 to 221. It contains appreciable quantities of nutrients like Ca, Mg, K and P. Biochar offers a medium having extremely high surface area (Figure 2) that improve adsorption properties and support microbiota, resulting in reduction of nutrient loss and increase in nutrient availability for the plants. The most important characteristic of biochar is the stability of its carbon in soil system. The stability of organic carbon is directly linked with its recalcitrant properties, interaction with organic and inorganic material that alters the decomposition and improves accessibility towards microbes and enzymes (Basak *et al.,* 2022). The recalcitrant mechanism is assumed to be the most important phenomena for sequestering carbon for longer period of time. Biochar is a carbonaceous material that contains significant amount of humic and fulvic acid along with polycyclic aromatic hydrocarbons. During formation of the porous, crystalline structure of biochar (Figure 2); nitrogen, phosphorus and other nutrients get absorbed from the feedstock. In that process, the leaching and volatilization of nutrients are inhabited but they are more bioavailable towards plants.

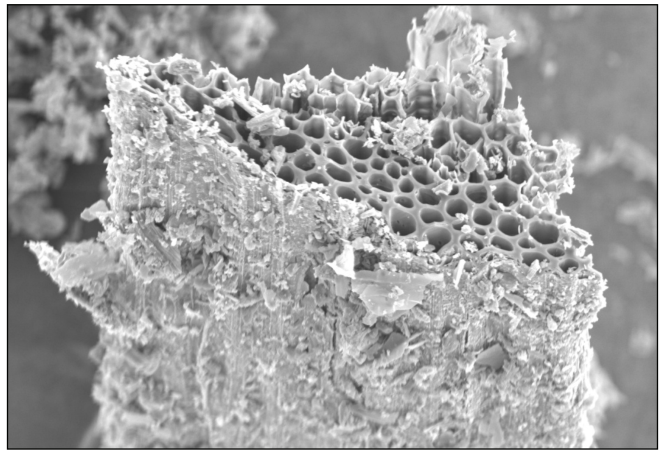

Figure 2: Surface morphology of biochar under scanning electron microscope

Benefits of Biochar in Farming System

Crop Productivity

Understanding the response of crops towards the biochar application rate is important for developing suitable strategy for sequestering carbon on long-term basis. Figure 3 depicted the immediate and long-term benefits of biochar application in agriculture and environment. It is reported that black carbon in combination with some fertilizers can produce significant benefits to agricultural soils as well as agricultural productivity (Saha *et al.,* 2019). The authors showed that in a high proportion of the studies (> 90%), apparent increase in yield was observed due to application of biochar, while Lehmann and Joseph (2015) reported significant improvements in plant productivity (20-

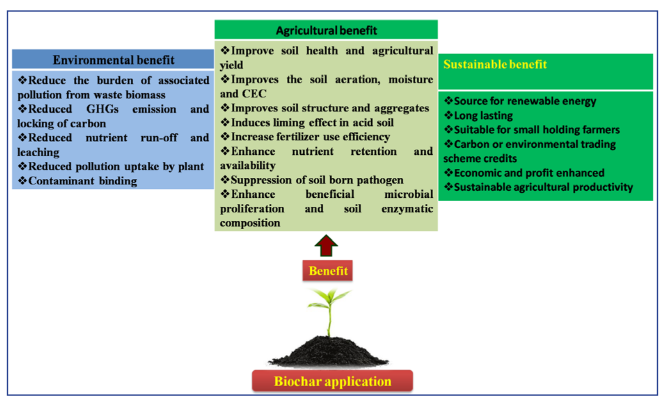

Figure 3: Agronomic and sustainable benefit of application of biochar

220%) depending on the amount of biochar added. Significant improvement in yield of rice, wheat, maize and raddish was observed with biochar amended fertilizer (Ding *et al.,* 2016). Other studies showed increase or decrease in plant yield, depending upon the quantity of charcoal added, crop tested and soil type over different short-term studies. Since no long-term studies carried out, so it is not clear whether the increased plant growth with addition of charcoal would be viable or sustained in longer term.

Soil Properties

Biochar improves soil physical chemical and biological properties by adding organic carbon to its ecosystem. It is well corroborated that biomass-derived black carbon (biochar) affects microbial populations and eventually the soil biogeochemistry. The symbiotic association between biochar and mycorrhizae in terrestrial ecosystems contributes towards sustainable plant production, restoration of ecosystem, carbon sequestration within soil and hence mitigation of global climate changes. Biochar also supplies some macro- (N, P, K, Ca and Mg) and micronutrients (Cu, Fe, Zn, Mn) which are required for sustainable production. Significant changes in soil quality, including improvement in organic carbon, pH and exchangeable cations as well as reduction in tensile strength were observed with higher rates of biochar application (Basak *et al*., 2022). The porous structure of biochar provides refugia for beneficial soil microorganisms such as bacteria and fungi (mycorrhiza). The porous nature of biochar also improve soil health by elevating processes like soil nitrification with added benefits of reducing of N_2O liberation ultimately reducing green house gas emissions.

Water and nutrient, the two major inputs in farming system are influenced by biochar application. Increases in soil organic matter is likely to increase soil water availability. Improvements in field capacity have been reported upon biochar application. Biochar application found to improve N use efficiency by reducing its loss through leaching and volatilization. Biochar can also improve P availability directly through anion exchange or by reducing the availability of the cations that interact with P. Biochar makes aluminium and iron oxides unable to react with available P which has linked with P fixation in acidic soils. There are conflicting evidences that the biochar application does little to contribute directly to the soil nutrient status; however, it can improve soil fertility *via* reduced nutrient leaching (Saha *et al.,* 2019).

Biochar for Environmental Sustainability

Biochar could be a sustainable way to increase the crop yield by reducing the reliance on chemical fertilizer. Thus, it can be future alternative for sustainable agricultural nutrient management. Conversion of large amount of waste into biochar is a carbon-negative technology which locking the carbon. This will not only solve the problem of waste management but also convert them into a valuable end product (Basak *et al*., 2022). Due to high specific surface area, biochar can immobilize the farm chemicals and rhizospheric heavy metals and thus inhibiting their movement into plant which not only increase the crop productivity, but also produce safe food for human consumption (Lehmann and Joseph, 2015). The major contributor of greenhouse gases (GHGs) emissions is the agriculture and amending soil with biochar may reduce the gaseous emission. In real field application also, biochar showed its effectiveness in improving various conditions like ecosystem quality, climate change mitigation and increasing resource use efficiency.

Conclusion

The production and application of biochar in soil is definitely a novel approach that has long-term beneficial effect towards soil health. Biochar acts as a promising matrix to hold carbon, minimizing the risk of carbon to return into environment that ultimately helps to improve soil health with minimizing environmental pollution. The vast scope and prospects of biochar in different aspects have been discussed that has proven to be an indispensible part of sustainable production system provided it requires long-term investment in agricultural experimentation. There is also need to monitor the changes in physical, chemical, hydrological and ecological indicators of the soil under the long-term application of biochar. Also, the response of different crops to biochar application under the different agro-ecological regions must be ascertained.

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