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Biochar: A Sustainable Solution for Reducing Greenhouse Gas Emissions

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Abstract

Biochar is a promising tool for climate-smart agriculture. It is a type of charcoal that is made from burning organic wastes in the absence of oxygen, which can help store carbon in the soil for thousands of years. When added to soil, biochar helps to improve soil quality, retain water, and sequester carbon, which can help to mitigate climate change. Biochar is also a renewable resource that can be made from agricultural waste products, which makes it a cost-effective and sustainable solution for farmers. By using biochar, farmers can increase their crop yields and reduce their greenhouse gas emissions, making agriculture more sustainable and climate-friendly. This article explores the benefits of using biochar in agriculture and its potential to promote climate-smart farming practices.

Keywords: Biochar, Production, Carbon sequestration, Greenhouse gas emission

Introduction

Greenhouse gas (GHG) emissions from soils are a key topic in global climate change issues, climate research and agricultural and forestry management. India produces 140 MT of surplus crop residue. A large portion of crop residue is burnt primarily to clear the field for sowing the next crop. Some of the conventional crop residue management methods result in GHG emissions, soil and water pollution, increase in soil temperature, loss of biodiversity and climate change. These crop wastes can be converted into biochar which can reduce GHG emission and increase crop health and productivity when applied to soil.

Biochar, the solid product of the pyrolysis of biomass, has been produced and utilized for several thousand years. The applications of biochar are very diverse, ranging from heat and power generation, flue gas cleaning, metallurgical applications, agriculture and animal husbandry, as building material and for medical use. It has gained increasing popularity during the last years as a replacement for fossil carbon carriers to reduce greenhouse gas emissions in several of these applications.

Biochar refers to black carbon that is produced as a vehicle of carbon sequestration from renewable and sustainable biomass. It is a stabilized, recalcitrant organic carbon compound created when biomass is heated to temperatures usually between 300 °C and 1000 °C under low oxygen concentrations. Biochar is being promoted primarily for climate change mitigation and for raising soil fertility. Biosolids, municipal waste, paper mill sludge, manure, agricultural residue, wood processing residue, algae and livestock/ poultry waste are some of the feedstocks used for biochar synthesis (Figure 1). The composition and quality characteristics of biochar such as recovery percentage, porosity, density, water holding capacity, nutrient content, CEC and pH are strongly influenced by the type, nature and origin of the feedstock.

Production of Biochar

Pyrolysis and gasification are the two different thermo-chemical conversion processes used to produce biochar from biomass. Pyrolysis is the thermo-chemical decomposition of condensed substances by heating under oxygen-limited conditions. In pyrolysis, a series of products such as biochar, bio-oils and syngas (fuel gas mixture of H_2, CO and CO_2) are derived. Slow pyrolysis is the thermal conversion of biomass by slow heating at low to medium temperatures (300-450 °C) in the absence of oxygen, with the simultaneous production of syngas. It yields more biochar than any other production

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Figure 1: Coconut frond and biochar

technology and retains up to 50% of the feedstock carbon. Fast pyrolysis is the thermal conversion of biomass by fast heating at high temperatures in the absence of oxygen, with the simultaneous production of syngas. Very rapid feedstock heating leads to a much greater proportion of bio-oil and less biochar.

There are several methods of producing biochar using pyrolysis, including the heap, drum, and kiln methods (Figure 2). In the **Heap method**, organic materials are piled up into a mound and covered with a layer of soil. The heap is then lit on fire, and the material in the centre of the pile is allowed to smoulder slowly over a period of days to weeks. This produces biochar, which can be mixed with soil to improve its fertility.

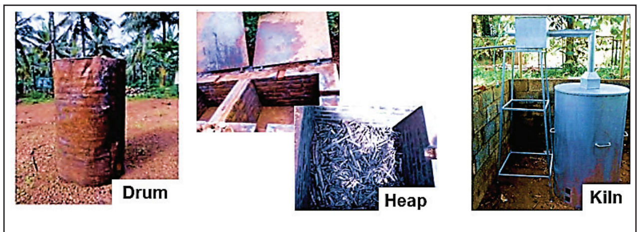

Figure 2: Method of production of biochar

The **Drum Method** involves using a metal drum with a tight-fitting lid. Organic material is loaded into the drum and heated from below using a wood fire or other heat source. The lid is then sealed, and the material is allowed to heat for few hours, producing biochar. The drum method is faster than the heap method and produces a higher quality biochar, but it requires more equipment and produces more emissions.

The **Kiln Method** is similar to the drum method, but it involves using a larger, more efficient furnace to produce biochar.

Gasification is the process by which any carbonaceous material (coal and petroleum as well as biomass) is substantially converted into a stream of carbon monoxide and hydrogen through a high-temperature (> 700 °C) reaction and controlled-oxygen environment, mostly at high pressures of 15-50 bars.

Properties of Biochar

Biochar is not pure carbon, but rather a mix of C, H, O, N, S and ash in different proportions. The main structure of biochar is a stacked crystalline graphitic sheet and randomly ordered amorphous aromatic structure. One of the most important physical properties of biochar is pore-size distribution. Macropores, mesopores, and micropores (pores with an internal diameter of > 50 nm, 2-50 nm, and < 2 nm respectively) constitute the total pore volume of the biochar. Biochar has large surface area ranging from 50 to 900 $m^2 g^{-1}$. It has a lower bulk density ranging from 0.3 to 0.43 g cm^{-3} due to biomass drying and carbonization leading to increased pore space and specific surface area. Typically, higher the bulk density of the feedstock used higher the bulk density of the produced biochar would be.

The reduction of functional groups during pyrolysis alters the material's affinity for water, and the increase in porosity alters the amount of water that can be absorbed. Water-holding capacity depends on the porosity of the biochar's bulk volume. Hydrophobicity is caused by the surface functional groups and biochar becomes more hydrophobic as the pyrolysis temperature rises since more polar surface functional groups are removed and thus the aromaticity is raised.

Presence of inorganic minerals like carbonates and phosphates, as well as the ash produced during pyrolysis and carbonization makes biochar typically alkaline.

Due to the incomplete decomposition of cellulose, some oxygen-containing functional groups, such as hydroxyl, carboxyl and carbonyl are retained during the carbonization process thereby increasing the cation exchange capacity of the biochar as compared to initial feedstock.

Effect of Biochar on Climate Smart Agriculture

Climate-smart agriculture is an approach for transforming and reorienting agricultural development under the new realities of climate change.

Effective climate change mitigation requires both reduction in GHG emissions and withdrawal of atmospheric carbon dioxide (CO_2) to achieve net zero emissions. The use of biochar as a soil amendment to reduce GHG emissions was first proposed as a global strategy for climate change mitigation 15 years ago and has been intensively studied over the past decade. Biochar has wider environmental applications due to its distinctive characteristics, *e.g.*, high adsorption capacity, high specific surface area, microporosity and ion exchange capacity. These characteristics of biochar eventually contribute to soil carbon sequestration and greenhouse gas emission reduction thereby contributing to an overall improvement in soil health.

1. Effect of Biochar on Carbon Sequestration

Carbon sequestration is the process of removing carbon from the atmosphere and depositing it in a reservoir. Biochar production and utilization systems differ from most biomass energy systems because the technology is carbon negative and carbon dioxide from the atmosphere is stored as stable soil carbon sinks in the terrestrial ecosystem. Biochar also reduces CO_2 emission which is achieved by reducing the requirement for fertilizers while increasing soil microbial life in turn resulting in more carbon storage in soil. Biochar may persist in soil for millennia because the carbon contained is very resistant to microbial decomposition and mineralization leading to a net sequestration of CO_2. It is one of the best technological solutions to reduce CO_2 emission levels since biochar has the potential to sequester almost 400 billion tonnes of carbon by 2100 AD and lower atmospheric CO_2 concentrations by 37 parts per million.

When carbon from biomass is converted into biochar, about 50% of the original carbon is stored compared to the small amounts of carbon retained after burning and biological decomposition. The estimated residence time of C from biochar in soils ranges from hundreds to thousands of years. Only a small portion of biochar carbon is bioavailable, and the remaining 97% directly contributes to long-term carbon sequestration in soil. The primary reason for the higher stability of biochar in soils is their resistance to microbial decomposition which is due to the presence of aromatic structures.

2. Effect of Biochar on Greenhouse Gas Emission

The GHGs *viz*., CO_2, methane (CH_4) and nitrous oxide (N_2O) are the main contributors to radiative forcing in the atmosphere. Besides anthropogenic activities (fossil fuel combustion, cement production and industrial procedures), the agronomic practices (drainage of wetlands, ploughing, land use conversion), fertilizer application, livestock and wetlands are important sources of GHGs. Sequestering carbon both in the vegetation and soil is the best method to mitigate GHG emissions. Conversion of biowastes into biochar and using this as a soil amendment is one of the best methods to sequester carbon into the soil. It increases the rate of nitrification, abundance of ammonium-oxidizing bacteria, nitrogen availability and reduces N_2O emission and NH_3 volatilization.

a) Effect of Biochar on Mitigation of Carbon Dioxide Emission

According to preliminary calculations, atmospheric CO_2 levels could be brought down to levels which existed before 1752 AD by 2050 if 2.5% of the world's agricultural land produces biochar, ideally from wastes for use in the topsoil. In an incubation experiment carried out by Jabin and Rani (2020) for 210 days on laterite and sandy soils of Trivandrum district of Kerala, all treatments receiving biochar either from rice husk or coconut frond resulted in lower CO_2 emission compared to treatments receiving FYM till the end of incubation period.

b) Effect of Biochar on the Mitigation of Methane Emission

Methane (CH_4), which makes up about 15% of all anthropogenically induced climate change and global warming, is the second most potent greenhouse gas after N_2O. It has a 28-fold greater potential for global warming than CO_2. Methane emissions are primarily biological in nature, accounting for 70 to 80% of total emissions.

Applying biochar to the soil has a significant potential for reducing methane emissions, which would further help to reduce GHG emissions. Pratiwi and Shinogi (2016) reported that on amending a paddy-cultivated soil with rice husk biochar at an application rate of 2 and 4% (w/w), a reduction of 45.2 and 54.9% respectively in total CH_4 emissions compared to the control was obtained. The effects of biochar on methane flux in the soil include methane adsorption on the biochar surface and increased methanotroph activity due to increased aeration and pH. Biochar increases the porosity of the soil and promotes microbial hotspot formation in its small porous structure, where the microbes can store methane for their metabolic activity thereby reducing methane emission.

c) Effect of Biochar on the Mitigation of Nitrous Oxide Emission

With 114 years of atmospheric residence time and a 265-fold higher global warming potential than CO_2, N_2O is a powerful GHG. It makes up about 5% of all global warming caused by humans. From 1961 to 2010, the global N_2O emission from agriculture increased by about 3 times from 1.44 Tg to 4.25 Tg. The largest anthropogenic source, accounting for 67% of all anthropogenic N_2O emissions, is agriculture. Of this 42% includes direct emissions from the management of manure and nitrogenous fertilizers and 25% indirect emissions from fertilizer runoff and leaching.

Biochar application in soil has been reported to reduce N_2O emissions which would further contribute to greenhouse gas mitigation. During the third wetting drying cycle in an incubation study conducted by Singh *et al.* (2010) using wood and poultry manure biochars synthesized at 400 °C and 550 °C in Vertisol and Alfisol, all biochar treatments consistently decreased N_2O emissions, cumulatively by 14 to 73% from the Alfisol and by 23 to 52% from the Vertisol, relative to their controls. Once applied to soils, biochar interacts with the soil to change the pH, oxygen content, microbial composition and activity, which results in a decrease in N_2O emission. Biochar application decreased the substrate concentration (NO_3^-, NH_4^+) for nitrification and denitrification reactions leading to reduced N_2O emissions. Additionally, it might also improve soil pH and N_2O reductase concentration, which would result in the final conversion of N_2O into N_2 and a decrease in N_2O emission.

Method and Dosages of Application of Biochar

Biochar should ideally be applied to the root zone, where the bulk of nutrient cycling and uptake by plants take place. If biochar was applied to soil solely for C sequestration purposes, placement deeper in the soil would be desirable since microbial activity that can degrade biochar carbon can be reduced. The likelihood of erosion losses of biochar is lower if it is thoroughly incorporated into soil. The different application methods are broadcasting, traditional banding, mixing biochar with other solid amendments, mixing biochar with liquid manures (Figure 3) *etc*.

Due to its recalcitrant nature, a single application of biochar to the soil can provide beneficial effects over several growing seasons. Therefore, biochar need not be applied to each crop successively like manures, compost, and synthetic fertilizers. Depending on the application rate, availability of biochar and the soil management system, biochar can be applied in different doses.

In general, biochar materials can differ widely in their characteristics, which in turn influence its application rate. Several studies have reported positive effects of biochar application at the rate of 5-50 tonnes hectare^{-1} along with appropriate nutrient management on crop yields. Though this is a wide range, when several rates were used, the plots with the higher biochar application rate showed better results. Most biochars when applied in combination with fertilizers can ensure further improvement in crop yield.

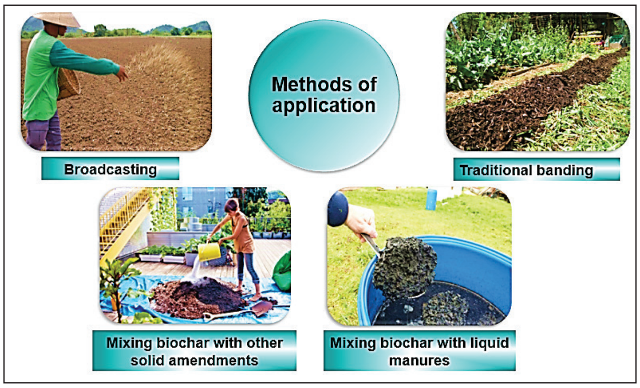

Figure 3: Method of application of biochar

Conclusion

Biochar is a rich form of stable carbon and a suitable option for mitigating climate change through long-term carbon storage and reduction in the emissions of GHGs like N_2O and CH_4. Apart from carbon storage, biochar also provides a sustainable solution for managing the large volume of crop residue without burning and thus prevent air pollution. Production of renewable energy and heat during biochar production and an increase in nutrient and water use efficiency when applied to soil further help in mitigating climate change through reduction in the emission of GHGs.

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