Biochar: an emerging soil amendment for sustaining soil health and black gold for Indian agriculture

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Abstract: At the international level, improving soil with coal is seen as a means to increase soil productivity, fertility and also to mitigate climate change. Biochar, which is used to increase land scope and store carbon, is currently gaining scientific attention and popularity in the agriculture sector. It is a solid material made by pyrolysis process of any biomass, including weeds, agricultural leftovers and other plant wastes, to carbonise it and use it as a soil amendment and carbon sequestration medium. Biochar is a viable option for enhancing soil chemical properties such as cation exchange capacity (CEC) and soil pH, as well as lowering exchangeable acidity. Biochar was also discovered to boost soil biota by boosting nutrient availability, improving habitat appropriateness, increasing water retention and aeration as well as lowering harmful compounds in the soil. Also, it can help to mitigate climate change by sequestering carbon in the soil and reducing nitrous oxide (N2O) and methane (CH4) gas emissions to the environment by enhancing soil absorption. However, several basic mechanisms and manipulations of biochar remain unknown and require further research.

Key words: Biochar, Carbon, Climate mitigation, Soil properties

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1. Introduction

As agricultural leftovers collect in fields, they can generate significant crop management issues and sometimes treated as a burden, owing to a lack of resources to turn it into an asset due that it is a growing issue in the Indian agricultural sector as well as in world. Hence, residue burning has traditionally been used to clear agricultural fields, allowing for easier land preparation and early planting. As a result, most Indian farmer's burn crop residue, resulting in the loss of valuable biomass and nutrients as well as the release of toxic gases such as CO2, N2O and methane, which contribute to global warming. Therefore, reducing crop residue burning and maintaining a threshold level of organic matter in the soil, on the other hand, is critical for the physical, chemical and biological integrity of the soil as well as long-term agricultural output. As a result, using the pyrolysis process to convert organic waste to biochar is one possible alternative for increasing natural rates of carbon sequestration in the soil, reducing farm waste and improving soil health. Biochar is a charcoal-like material made from plant materials such as grass, agricultural and forest leftovers that degrade at high temperatures, usually during the creation of renewable energy. The physical and chemical properties of the plant material change during the process, resulting in biochar, a highly porous, stable, carbon-rich substance. This is 2,000 year old method transforms agricultural waste into a soil amendment that can store carbon, increase soil biodiversity and reduce deforestation. Biochar is a fine-grained, highly porous charcoal that helps soils retain nutrients and water while also retaining carbon. The use of biochar as soil amendment is proposed as a new approach to mitigate man-induced climate change along with improving soil productivity. Biochar is currently a subject of active research global because it is able to constitute a feasible alternative for sustainable agriculture due to its ability as a long term sink for carbon in soil and blessings for crops. Pyrolysis is a thermo-chemical system where biomass is heated in the absence of oxygen, whereby the resulting char is normally stabilized carbon. When this char is intentionally produced for agricultural or environmental use it's far called biochar. Biochar manufacturing from agricultural waste and its use in agriculture can play a key function in climate change mitigation, improve the soil quality and management of waste substances coming from agriculture and forestry (Zhang et al., 2012). It was observed that application of biochar improves soil physical, chemical and soil biota characteristics by increased soil pH, cation exchange capacity, soil water holding capacity, permeability and modify soil bulk density, aggregate stability. Biochar may also adsorb pesticides, nutrients and minerals in soil, preventing the movement of these chemicals to surface water or groundwater and the subsequent degradation of these waters from agricultural activity. Biochar has also been validated to reduce methane and nitrous oxide emissions from agricultural soils, which give a bonus in mitigating climate change effects. These environmental welfare shave great economic value in the form of boosting agricultural production and productivity, safeguarding water quality protection and a bridged the emission of greenhouse gasses. Due to its multiple benefits, biochar has acquired attention from climate and policy analysts. Therefore, this paper reviews the role of biochar in soil physical, chemical and biological property as well as climate change mitigation.

2. Review of the Literature

2.1. Effect on soil physical properties

The fact that most of carbon in biochar is summarized aromatic and intractable, a small fraction of it less than 10% is labile and available for microbial decomposed (Wang et al., 2017). As an example, Steiner et al. (2007) noted that 4-8% of biochar carbon was lost during four cropping cycles in a field trial in Manaus, Brazil. In fact, carbon from biochar plays a key role in soil aggregate stability based on mean weight diameter measurement. Liu et al. (2014) applied 40 t/ha of a wheat straw biochar to a red soil of southern China and reported that the soil water stable aggregate (>0.25 mm) was enhanced by 28% over the control. Similarly, Wang et al. (2017) showed a remarkable improvement in aggregation of a fine texture soil with 217% and 126% average increases in mean weight diameter when incubated for 60 weeks with a softwood biochar. The result of experiment conducted at Navsari (Gujarat) by Patel in 2019 revealed that application of 2.5 t/ha biochar had positive effect on moisture retention capacity of clay loam soil at different tension over control. Biochar have high porosity, which was caused by the pyrolytic emission of structural water and the decomposition into gases of feedstock tissues (e.g., cellulose, lignin, proteins). With numerous and variable pores, biochar help reduce the bulk density and increase the water holding capacity of the amended soil (Duong et al., 2017). Thus, adding biochar at common rates of 0.5-5.0% to mineral soils having an average bulk density of 1.2 g/cm3 will reduce the overall bulk density of the amended soil significantly (Laird et al., 2010). An experiment conducted by Case et al. (2012) reported that soil bulk density decreased from 0.95 g/cm3 to 0.89, 0.87, and 0.84 g/cm3 with the application of 2, 5, and 10% of a hardwood biochar, respectively. Chaudhary et al. (2016) reported that application of biochar 12 t/ha significantly lowered bulk density of fine texture soil due to high porosity of biochar. The experiment conducted by Duong et al. (2017) showed that 1% biochar made from rice husk or coffee husk increased the water holding capacity of a sandy gray soil of Vietnam by 26-33%. Also, Gowthami et al. (2019) noticed that with increasing the rate of biochar from 2, 4 and 6 t/ha, increased porosity and WHC as well as decreased bulk density of acidic red sandy loam soil was observed. Similarly, bulk density, porosity and WHC of plinthustults soil significantly improved with application of biochar 10 t/ha were observed in an experiment conducted by Rajakumar and Sankar (2019) at Kerala.

2.2. Effect on soil chemical properties

Biochar is currently a subject of active research worldwide because it can constitute a viable option for sustainable agriculture due to its potential as a long term sink for carbon in soil and benefits for crops. Significant increment of organic carbon content was reported from a number of studies. Significant increase in organic carbon content in calcareous loamy soil recorded with the application of 40 t/ha biochar over control (Zhang et al., 2012). With increase in biochar rates up to 12 t/ha the organic carbon content in loamy soil was increased significantly (Chaudhary et al., 2016). During an experiment on impact of biochar at Colorado, post-harvest total organic carbon content in portneuf silt loam soil were significantly enhanced with 22.4 Mg/ha biochar + 42 Mg/ha manure over control (Khalid et al., 2016). Similarly Ullah et al.(2018) noticed that application of 10 t/ha biochar prepared from wheat straw and sugarcane significantly improved the organic carbon content in sandy soil as compared to control.

Biochar alkalinity can come from four sources: surface functional groups, soluble organic compounds, carbonates and other inorganic alkalis (Fidel et. al., 2017). As an example, Xu et al. (2012) reported an increase over 2 pH units, from 5.0 to more than 7.0, when 5% peanut shell biochar was applied to four acid soils of southern China. Also, application of the biochar prepared from different sources (Ageratum conyzoides, Lantana camera, Gynura sp., Setaria sp., Avena fatua, Maize stalk and Pine needles) had positive and significant impact on improvement of soil pH. Irrespective of the sources of biochar, its application improved soil pH by 0.26 to 0.30 units within 2 months (Mandal et al., 2015). The alkaline pH of most biochar, incorporating biochar into acid soils can increase soil pH up to 73% with an average increase of 28% (Mukherjee and Lal 2017). Similarly, in 2018, Wakjira noticed that increasing biochar application rate 52, 104 and 156 Mg/ha prepared from corn stover and switch grass significantly increased soil pH of acidic soil over control. The cation exchange capacity will be markedly increased when biochar is aged and is mixed with soil. The possible reason for increased in CEC due to the amendments of biochar might be high surface area, high porous, possesses organic materials of variable charge that have the potential to increase soil CEC and base saturation when added to soil (Glaser et al., 2002). Many studies have shown that soil CEC may increase up to 30% on average. Laird et al. (2010) indicated that the biochar treatments significantly increased cation exchange capacity by 4 to 30 % compared to the control. Available evidences also suggest that, the intrinsic CEC of biochar is consistently higher than that of whole soil, clays or soil organic matter (Sohi et al., 2010). Similarly, Mukherjee et al. (2014) reported that after aging for 15 months, biochar made by pyrolysis of wood (oak and pine) and grass at 250, 400, and 650 C exhibited fivefold increases in CEC. Nutrient entrapment caused by porous structure, and high water holding capacity has been suggested as a responsible mechanism for anions, such as nitrate and arsenate retention (Ippolito et al., 2015). Similarly, Chaudhary et al. (2016) reported that application of 12 t/ha biochar with and without RDF showed significantly higher CEC of loamy soil.

Besides being an efficient adsorbent, biochar itself contains nutrients. Depending on feedstock and pyrolysis process and also on individual nutrient, nutrient availability may be immediate or gradual. For example, biochar derived from animal manure or grass and pyrolyzed at lower temperature release more nutrients than those made from woody biomass (Mukherjee and Zimmerman, 2013). Over 50% of total K in biochar is water soluble and readily bio-available. Thus, biochar can be a good source of K for crop uptake, especially in organic farming (Martinsen et al., 2014; Butnan et al., 2015). For example, an increase of 7% in N mineralization was obtained when 5% of a wheat straw biochar was mixed with a sandy loam soil, while a 43% reduction was resulted from the application of the same feedstock but fast pyrolyzed biochar after 65 days of incubation (Bruun et al., 2012). Similarly, the direct contribution of N from biochar has a mixed result, particularly in terms of plant responses (Gul and Whalen, 2016).

2.3. Effect on soil biological properties

The porous structure of biochar, its large internal surface area, and its high capacity to retain water provide favorable habitats for soil biota (Jaafar et al., 2015). Bacteria (size 0.3–3 mm) and hyphae (<16 μm) of different fungi can colonize biochar macro-pores (sizes of 2 mm-2 μm are common) and avoid predators, such as mites and nematodes (Ezawa et al., 2002; Jaafar et al., 2015). In addition, water is essential to all living organisms, and its presence in biochar pores would enhance the microbial habitability (Batista et al., 2018). Increased enzyme activity of dehydrogenase, β-glucosidase, and urease in a red soil of China was recorded when amended with an oak wood or bamboo biochar at 0.5, 1.0, and 2.0% after 372 days of incubation (Demisie et al., 2014). Luo et al. (2018) showed that all microbial groups (Gram positive and Gram-negative bacteria, Actinobacteria and Fungi) were more abundant in the biochar treated soil after 14 months of incubation. Similar findings were reported by Gomez et al. (2014) in a study using four soils from the Midwest, USA, and concluded that biochar stimulated microbial activity and growth. Chen et al. (2013) found that gene copy numbers of bacterial 16S rRNA was increased by 28% and 64% and that of fungal 18S rRNA decreased by 35% and 46% under biochar applications of 20 and 40 t/ha, respectively, over the control in a rice. Bera (2016) reported microbial biomass carbon content in post-harvest inceptisol soil found significantly the highest with application of rice straw biochar 6.75 g/kg soil. A field experiment was conducted by using biochar prepared from Dalbergia sissoo wood by brick batch process revealed that application of 100% RDF +12 t/ha biochar gave significantly the highest soil microbial biomass carbon in loamy soil (Chaudhary et al., 2016). Pandian et al. (2016) stated that application of biochar from various sources and rate in sandy loam soil significantly improved bacteria activity in soil as compared to control.

2.4. Role in climate change mitigation

Climate change is one of the chief intimidations to agriculture in the vicinity of futures. Its most apparent effects would be on temperature, precipitation, insect pest and pathogen, weeds soil and water quality. It observed that agricultural activities contribute 25% greenhouses gas emission and major source of methane (48%) and nitrous oxide (52%) from rice fields. Therefore, strong action should be carried out to reduce emissions and increase removal of greenhouse gasses from the atmosphere. Biochar has been described as a possible means to sequester carbon to mitigate climate change. Biochar counteract climate change problems by the following two key ways. Firstly, by its molecular structure, in which chemically and biologically more stable than the original carbon form, which making it more difficult to be converted back to CO2, meaning it can store carbon for a long time. Most recently, Woolf et al. (2010) predicted that sustainable biochar systems could amount to net avoided emissions of up to 1.8 Gt CO2-Ce a year, for total net avoided emissions of 130 Gt CO2-Ce over 100 years. Secondly, biochar in soil change emissions of other greenhouse gases from soil such as nitrous oxide (N2O) or methane (CH4). A three years trail by Rondon et al. (2005) on soybean crop was found 50 % reduction of N2O emission from the soil, when biochar applied at the rate of 20 t/ha compared to control. Spoaks et al. (2009) found that N2O emission significantly reduced at the higher rate (20 - 60 t/ha) of biochar. Yami et al. (2007) observed that N20 emission was dependent on soil moisture content. The water pore space filled up to78% reduced the emissions of by 89% when biochar was added, compared to the control. Conversely, when the soil pore space filled by water up to 83%, reduced N2O emission nearly by 50% when biochar incorporated.

3. Conclusion

Soil organic matter and fertility status of Indian soils are declining over the decades because of climatic variability and imbalances in fertilization practices. Improving the soil health, nutrient status, and productivity of crops in India is a critical need for ensuring sustainable agricultural development in India. Therefore, biochar has the potential to improve soil CEC, soil acidity, microbial biomass, carbon sequestrations, mitigate greenhouse gases emissions, and remediate heavy metals toxicities, which in turn provides favorable growing environments for crops. Application of biochar from crop residue can also offer additional carbon negative benefits through avoiding burning in fields and bio resource recycling, however, these mechanisms remain unclear. Only few studies have investigated the effects of biochar on plant nutrition and yield under field conditions. Therefore, understanding the mechanisms and exploitation of biochar remains challenging.

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