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Review Paper

Biochar – an Essential Component for Soil Enhancement, Plant Development and Environmental Cleanup

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Abstract: Biochar is a solid, carbon rich product produced by thermal decomposition of organic matter in the absence of oxygen. It is persistent and beneficial to the soil. This review systematically analyzed and summarize the beneficial aspects of biochar for soil quality improvement, plant growth and environmental remediation. Also, this review provides an overview of the research conducted on biochar till data in Nepal. Study reported the effects of biochar depend on the quality of materials and the type of soil where it is going to be utilized. If site-specific soil limits and nutrient/water limitations are reduced by proper biochar formulations, crop yields significantly rise. The application of biochar in carbon sequestration should be further investigated at similar experimental conditions to obtain consistent results. A study suggested that the effect of biochar on soil microbes should be further investigated to elucidate the dominant reason for the improvement of soil fertility based on different soil and feedstock. In summary, biochar has a wide application prospect in environmental remediation and should be further investigated.

Keywords: *biochar, carbon sequestration, plant growth, soil fertility*

Introduction

Soil fertility is critical as it can influence the crop yields and their development. The fertility can be improved through organic and inorganic fertilizers in the soil. It incorporates a number of soil characteristics (biological, chemical and physical), all of which have an impact on the availability and dynamics of nutrients either directly or indirectly. Since the "green revolution", inorganic fertilizer have significantly increased agricultural productivity (Liu et al. 2010); nevertheless, they are not a sustainable option for the maintenance of crop yields (Vanlauwe et al. 2010). Mineral fertilizer used excessively over time may increase soil acidification, impacting both soil biota and biogeochemical processes, posing a risk to the environment and reducing agricultural yield (Aciego Pietri and Brookes 2008). Therefore, organic additives like compost and biochar may be helpful in preserving and improving soil fertility and crop yield.

Biochar is a black, stable, carbon-rich material thermochemically converted (slow, intermediate, and fast pyrolysis or gasification) in an oxygen-limited environment. A variety of feedstocks, including agricultural and forestry wastes, may be used to make it, including straw, nutshells, rice hulls, wood chips and pellets, tree bark, and switchgrass (Sohi et al. 2009). Biochar can be used as a possible tool for removing toxicity from soil and help in climate change mitigation (Ennis et al. 2012; Stewart et al. 2013). Several studies have shown that biochar application to soil can (i) improve soil's physical and chemical properties (Sohi et al. 2010; Mukherjee and Lal 2013) (ii) enhance plant nutrient availability and correlated growth and yield (Jeffery et al. 2011; Biederman and Stanley Harpole 2013) (iii) increase microbial population and activities (Lehmann et al. 2011; Jaafar et al. 2014), and (iv) reduce greenhouse gas emissions through C sequestration (Crombie et al. 2015). Studies have shown that combined applications of biochar with organic or inorganic fertilizers could lead to enhanced soil physical, chemical, and biological properties, as well as plant growth. Several composted materials in particular offer a sustainable supply of nutrients that might promote plant development while improving the physicochemical and microbiological qualities of the soil (Schulz and Glaser 2012; Liu et al. 2012).

According to Liu et al. (2012), compost and biochar applied together exhibit a beneficial synergistic effect on soil nutrient levels and water-holding capacity under field conditions.

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Also, the use of biochar in conjunction with compost has shown to be effective in stabilizing soil structure, increasing soil nutrient content, and enhancing water retention capacity (Schmidt et al. 2014; Agegnehu et al. 2015). Moreover, these studies highlight how the combination of compost and biochar might improve the qualities of compost, resulting in a greater added value and a far better potential for carbon sequestration because of the long-term stability of biochar (Schulz and Glaser 2012).

However, research indicates that depending on the types of feedstock used, the production and the application process used, can differ soil biophysical-chemical characteristic and plant growth and yield (Bernal et al. 2009). The review provides a overview of importance of biochar as a key component for the improvement of soil and crop production.

Biochar for soil enhancements

Biochar is a carbon-rich material that contains organic matter, inorganic salt (humic and fluvic substance), N, P, and K that may be used as fertilizer and taken up by plants and microbes. According to Lin et al (2012), humic levels in biochar made from *Acacia saligna* at 380 ^{o}C and sawdust at 450 ^{o}C were 17.7 and 16.2%, respectively. Biochar made from *Lantana camara* at 300 ^{o}C contained available P (0.64 mg kg^{-1}), available K (711 mg kg^{-1}), available Na (1145 mg kg^{-1}), available Ca (5880 mg kg^{-1}) and available Mg (1010 mg kg^{-1}) (Masto *et al.* 2013). Similarly, fresh biochar had the potential for nutrient availability and could release large amounts of N (23 – 635 mg kg^{-1}) (Mukherjee & Zimmerman 2013). Biochar not only increases nutrient content but also increase available water capacity, soil porosity (Nelissen et al. 2015) and increase crop production and prevent soil degradation (Amézketa, 1999). Lu et al., (2014) showed an increase in soil aggregation (8 to 36%) and soil pore structure (20%) after the application of rice husk biochar. These studies show that biochar has great potential to be utilized as nutrient-rich organic fertilizers.

Enhanced physicochemical characteristic of soil

Application of biochar to soil can increase soil aeration, bulk density, porosity, and packing, as well as increase net soil surface area (Chan and Xu 2012; Palansooriya et al. 2019). Additionally, through improving soil aggregate stability, soil preparation workability, water infiltration, and water holding capacity, biochar directly modifies the connection between soil and water (Qambrani et al. 2017; Purakayastha et al. 2019). This improvement in soil quality is made possible by the movement of water, heat, and gases on soil and the decrease in bulk density and rise in soil porosity (Lian and Xing 2017). Moreover, biochar affects soil pH, which is particularly beneficial in reducing soil acidity by enhancing cation exchange capabilities (K, Ca, Mg, and Na from biochar), through functional group effects (–COO– and -O- contribute greatly to biochar alkalinity) and increase the availability of primary and secondary nutrients like K, P, Ca, Mg (Kookana et al. 2011). According to (Laird et al. 2010), biochar increased cation exchange capacity, amount of nutrients that are available to plant roots, which promotes microbial activity and quickens chemical reaction in the rhizosphere.

Improvement in soil fertility

Through the cycling of soil organic matter, biochar has been proven to alter soil biological qualities in addition to improving soil physicochemical properties (Liang et al. 2010). It can optimize nutrient cycles, increase pore space, and improve soil structure, all of which will lead to nutrient retention and immobilization and eventually promote plant development (Warnock et al. 2007). By cycling soil organic materials, microorganisms like rhizosphere bacteria and fungus may directly promote plant development. According to Domene et al. (2014), the addition of 30 t ha^{-1} biochar might cause an increase in microbial abundance from 366.1 to 730.5 µg C g^{-1}. Similarly, for the various preincubation durations (2 – 61 days), microbial abundance rose by 5 – 56% with the rise in maize stove biochar rates (from 0 to 14%) (Domene et al. 2015). The possible reason for the increase in microbial abundance is due to higher availability of nutrients, less competition, increased habitat suitability and refuge with the addition of biochar.

The kind of soil and the amount of biochar have an impact on the microbial community in the soil. Biochar may include certain organic pyrolytic products that are toxic to soil microbes, such as phenolics and polyphenolics. After the application of biochar, a research by Warnock et al (2007) revealed a reduction in mycorrhizae and overall microbial biomass. Microbial abundance and activities are reduced due to the retention of heavy metals and pesticides released from biochar (Gell et al. 2011). Additionally, certain biochar may directly risk the soil biota and their functions, resulting in lower crop yields (Liesch *et al*., 2010). Clover plant leaves have reportedly been discolored as a result of biochar application without sufficient washing to remove organic and inorganic contaminants (Turner, 1955).

More research is needed on fundamental mechanisms and the utilization of biochar is poorly understood. Therefore, research should focus on the following aspects.

- Studying how soil microbes and biochar interact, with a particular emphasis on how much CH_4 and $N_2O$the soil release as greenhouse gases.
- Many factors restrict the use of biochar and soil and its application rates; therefore, field trials should be conducted by selecting a suitable variety to understand the interaction between biochar, soil, microbes, and plant roots.
- Since the life cycles of biochar in the soil are not well known, we should focus more on how quickly biochar decomposes in the soil.

Biochar for environmental remediation

Biochar can be used as a remediation product to lessen soil pollution in addition to enhancing soil fertility. For the purpose of cleaning up polluted soils, biochar in soil exhibits a variety of interactions with inorganic and organic contaminants (Younis *et al*., 2016).

Removal of heavy metals

Heavy metals are an environmental pollutant and is hazardous when they accumulate in the organism. It has been proposed to utilize biochar to remove heavy metals from polluted water. Removal mechanisms vary depending on the valence state of the target metal at different solution pH (Li *et al*., 2017). Numerous studies have demonstrated that the capacity of biochar to reduce pollution is due to a variety of functional groups and inorganic ions contained in the biochar, which may greatly aid in stabilizing metals in soils in addition to the surface sorption (Xu et al. 2013; Wang et al. 2018). A study by Zhang *et al*. (2015) showed that there was almost an equal amount of sorption of Cd and total released cations (Na, K, Mg, Ca) from the biochar, indicating the cation exchange has a leading role in Cd sorption. Zhou et al (2013) showed that the biochar modified by chitosan had favourable removal efficiency for three heavy metals (Cd^{2+}, Pb^{2+}, and Cu^{2+}) from solutions. Two dyes used in wood carpet dyeing (Lanasyn Orange and Lanasyn Gray) could be highly sorbed on nanoporous biochar derived from bamboo cane (Pradhananga *et al*., 2017).

Removal of pesticides

Biochar can be used to remediate pesticide pollution in a novel way, restoring ecological balance and enhancing human health (Dai et al. 2019). According to Klasson et al. (2013), almond shell biochar has 102 mg g^{-1} sorption capacity for the nematode pesticides dibromochloropropane. Thiacloprid was reported to be absorbed by biochar made from maize straw through pore-filling and hydrophobic interaction (Zhang *et al*., 2018). Sawdust char helps to eliminate more than 89% of Tetracycline (Zhou *et al*., 2017).

Removal of antibiotics

Pharmaceutical wastewater is classified as an emergent environmental concern since it takes a long time for it to break down naturally (Carvalho & Santos, 2016). The research was conducted on reducing the toxicity of antibiotics by biochar. Humic acid-coated magnetic biochar derived from potato stems and leaves sorb three typical fluoroquinolones (FQs) i.e. enrofloxacin (ENR), norfloxacin (NOR), and ciprofloxacin (CIP) by hydrophobic, electrostatic, and formation of hydrogen bonds (Zhao et al. 2019). To enhance sand biofilters, Mohanty *et al*. (2014) added 5 wt% biochar to increase the *Escherichia coli* removal capacity and prevent their mobility during continuous, intermittent flows.

Nepali biochar research efforts

In Nepal, there has been some study and there is some understanding about the use of biochar. There are very few peer-reviewed journal papers based on extensive biochar experiments in Nepalese soils. Nepali farmers are traditionally practicing open-burning of agricultural wastes before the cropping season with a belief that ashes of biomass help enrich soils. There are many researchers conducted by Nepalis researchers in temperate climate countries of Asia (especially in China, Indonesia, and Japan), Europe, Australia, the USA and South America but they are not based on Nepalis soils. Also, field experiments conducted in one part of the world could not be the same in others due to diverse soils and climates. According to Mukherjee and Lal (2014), biochar advocacy is growing worldwide without adequate scientific knowledge on basic soil processes and cost-benefit analysis of biochar application to soil. Therefore, more research on biochar is needed despite its beneficial effects on the soil environment particularly to assess its effectiveness in different soil profiles, climatic conditions and crop varieties. In Nepal, there is a volume of renewable feedstock from agriculture and forest which is critical sources for promoting biochar. We can choose the feedstock which is underutilized biomass available from farm fields, households, and markets of agro-processing mills. As our focus is on the hill economy, we can choose available forest litter and invasive species of grass and shrubs as also ricks husks and wooden dust from mills. The feedstock can be chosen depending on seasons and ecological conditions.

Table 1: Agencies undertaking biochar programs in Nepal.

Agency	Types of activity	The funding source, program areas, years, and key interventions
Asian Development Bank in collaboration with Nepal Agriculture Research Council and Nepal Academy of Sciences and Technology	Action research, piloting	Nordic Development Fund, 3 eco-regions – high mountains, mid-hills and Terai, 2014 -16, production tests, trials on soil amendment, carbon sequestration, and energy-saving stoves.
Department of Environment Science and Engineering, Kathmandu University	Action research	Helvetas Intercooperation, Sindhupalchok, Kavre and Lalitpur of Nepal, 2013-15
Multi-stakeholders Forestry Programme	Community support	Jointly funded by Swiss, UK and Finland, 2013-14, support communities of smallholding farmers for livelihood improvement
Nepal Agroforestry Foundation	Scientific research	Norwegian Geotechnical Institute and the Norwegian University of Life Sciences, 2012 onwards. Nepal is one of the 4 countries where the project has been launched.
Local Initiative for Biodiversity Research and Development	Action research, piloting	DanChurchAid, 2014-2016, support for livelihood improvement among low-income households

Prospects for using biochar

Biochar is not widely applied and is still in the test stage of research. Due to a lack of an industrial chain and public awareness, biochar utilization is still undeveloped in developing nations. Therefore, laborious research work should be carried out to address potential environmental issues and broaden the uses of biochar. Despite being plentiful and widely accessible, feedstock/biomass must be properly ground, cleaned, and pyrolyzed to produce biochar. Therefore, to reduce the cost, future research should attempt to find a compromise between optimizing the production process and maximizing the applicability of biochar. To get biochar with improved performance, study should also be done on the careful selection of feedstocks, manufacturing circumstances, and modification techniques. More efforts would be needed to link biochar properties to soil and crop responses in both climate-controlled environments and in the field.

Conclusion

The addition of biochar to soil has enormous promise for enhancing soil fertility, fostering plant development, and cleaning up the environment. To comprehend biochar true function in soil fertility and biomass output, the type of biochar sued should be flexible. The study demonstrated the biochar has a significant surface area, an intricate pore structure, and levels of exchangeable cations and nutritional components. Therefore, biochar should be considered as catalyzers, not as a fertilizer. Biochar offers an alternate method for increasing agricultural land productivity as well as for sequestering carbon through increased organic matter in soil that has been locked for generations.

Lastly, biochar research could provide very positive effects in improving soil quality and crop productivity in Nepal as the agriculture and forest sector offers a huge number of resources.

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