Role Of Biochar in Soil Health and Crop Production

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Introduction

One of the primary drivers of climate change is the excessive accumulation of carbon dioxide (CO_2) and other greenhouse gases in the atmosphere. Biochar offers a unique solution to this problem by sequestering carbon for long periods. When produced through pyrolysis, biochar is highly stable, with its carbon content remaining locked in the soil for hundreds to thousands of years, preventing the release of CO_2 back into the atmosphere. This ability to store carbon effectively makes biochar a critical tool in reducing the carbon footprint and mitigating global warming. Additionally, biochar can help reduce greenhouse gas emissions from agricultural practices. It improves soil health by reducing nitrous oxide emissions, a potent greenhouse gas that is often released from fertilized soils. As a result, biochar can contribute to the development of more sustainable agricultural practices that are both carbon-efficient and environmentally friendly.

Soil health is at the core of global food security. With declining soil quality, including nutrient depletion, erosion, and acidification, the ability of soils to support healthy crops is increasingly compromised. Biochar can play a pivotal role in reversing soil degradation. When added to soil, biochar improves soil structure, increases nutrient retention, enhances microbial biodiversity, and boosts water-holding capacity. These benefits result in healthier soils that are more productive, requiring fewer chemical inputs like fertilizers and pesticides.

Biochar

The history of biochar is associated with the discovery of Terra Preta di indio (black earth) in the Amazon basin. "Biochar is a solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment". It is produced through thermochemical processes, such as pyrolysis, torrefaction, gasification and hydrothermal processing. This carbon-rich material, derived from organic waste like agricultural byproducts and sewage sludge, features high carbon content, cation exchange capacity, and structural stability, making it valuable for various applications (Wang and Wang 2019).

Classification

The biochar has been categorized into six types based on the primary biomass source from where it is produced (Aller, 2016).

(i) Lignin-rich biochar: Derived from high-lignin content biomass, including tree parts, wood, and sawdust.
(ii) Cellulose-rich biochar: Produced from biomass where cellulose is the main structural component, such as grasses, straws, and grains.
(iii) Nuts/shell biochar: Created from materials that protect nuts, like husks and shells.
(iv) Manure/Waste biochar: Obtained through pyrolysis of manures, biosolids, or green waste.
(v) Algae biochar: Generated from fresh and seawater algae.
(vi) Black carbon: Encompasses other biochar types produced from biomass not included in the above categories and naturally occurring black carbon forms

Properties

Biochar's unique physico-chemical properties, such as surface area, pH, and nutrient concentrations, vary by feedstock and production temperature (Gul *et al.*, 2015). Fast pyrolysis increases surface area but not the C:O ratio. Biochar properties has a greater influence on soil nutrients, carbon availability and microbial diversity (Lehman *et al.*, 2011). Biochars from seaweeds, manures, and crop residues are nutrient-rich with higher pH but less stable carbon than wood-based biochars. Pyrolysis conditions significantly shape biochar's applications (Chun *et al.*, 2021).

Applications

Biochar, with its significant surface area, remarkable stability, and catalytic properties, stands out in environmental applications such as soil remediation, carbon sequestration, and pollutant removal. Originating from its recognition in the historic *terra preta* soils, biochar has gained acclaim for its ability to enhance degraded soils, boost agronomic productivity, and contribute to carbon trading initiatives (Spokas *et al.*, 2012). Beyond its impact on soil health, biochar demonstrates versatility in various fields, including water purification, air filtration, construction materials, and more—underscoring its immense potential in advancing sustainable practices. In soil, application of biochar can help prevent nutrient loss due to erosion or runoff in degraded soils (Jien., 2019). It is widely recognized as an effective tool for carbon sequestration and improving soil fertility (Jindo *et al.*, 2014). When incorporated into soil, biochar is expected to enhance the overall sorption capacity towards anthropogenic organic contaminants such as polycyclic aromatic hydrocarbons (PAHs), pesticides, and herbicides, in a stronger and mechanistically different way compared to amorphous organic matter.

Biochar can be incorporated into topsoil alone or with composts/manures. In tillage systems, it's mixed into 0–15/30 cm depth, while top-dressing spreads it on the surface for natural integration. Deep-banding places biochar in the rhizosphere, benefiting crops and reducing erosion. Application methods include pneumatic systems or furrow placement, with frequencies ranging from single to annual applications based on desired effects like nutrient availability or reduced nitrate leaching.

Biochar enhances soil fertility

Biochar improves agricultural productivity by enhancing soil fertility, raising pH in acidic soils, boosting cation exchange capacity (CEC), and supporting microbial activity and nutrient retention (Kookana *et al.*, 2011). It provides nutrients like N, P, and K and aids nitrogen retention by adsorbing ammonia (NH_3) and ammonium (NH_4^+) (Sohi et al., 2010). Studies show biochar improves fertilizer efficiency, soil structure, and microbial diversity, especially in forest soils. Enhanced soil fertility increases CO_2 uptake, reduces fertilizer emissions, and improves water retention and nutrient availability through soil mesoporosity and organic coatings. Co-composting with biochar ensures a gradual nutrient release, optimizing soil benefits (Qian *et al.*, 2015).

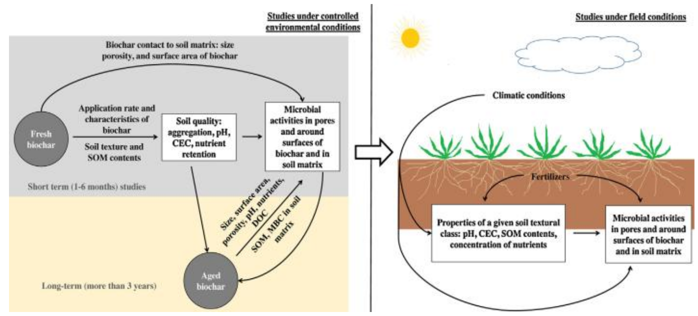

Fig. 2. A conceptual framework for exploring ideas/hypotheses about influence of biochar on soil physico-chemical properties and microbial activities as function of interactive effect of its characteristics such as size, porosity, surface area, nutrient contents and pH and soil native characteristics as texture and residual SOM contents (left side) (Gul *et al.*, 2015).

Incorporating biochar into soil can significantly boost its organic matter content, thereby enhancing soil fertility, as evidenced in the terra preta. Crops in the Brazilian Amazon's terra preta grew three times faster compared to those in neighboring soils. The application of biochar can also impact soil's physical characteristics, such as water retention and aggregation, which play crucial roles in plant development (Xu *et al.*, 2012). Introducing biochars to soils has been shown to affect their structure, texture, porosity, particle size distribution, and density. Furthermore, biochar addition can decrease soil acidity while increasing soil electrical conductivity and cation exchange capacity (CEC), leading to improved nutrient availability (Laird *et al.*, 2010).

Carbon sequestration

The issue of global warming urgently requires that effective measures are taken to augment carbon sequestration and decrease the CO_2 concentration in the atmosphere. Making waste biomass into biochar leads to carbon sequestration due to the stable and carbon-rich nature of biochar (Zhang *et al.,* 2018). Biochar can not only sequestrate carbon following its application in soil, but also reduce the amount of released CO_2, N_2O, and CH_4 in the soil, thus helps to alleviate the greenhouse effect. In order to achieve better carbon sequestration effect, biochar should be applied in neutral and alkaline soils rather than in acidic soils due to accelerated degradation of soil organic carbon and biochar.

Boosting crop growth

The research has suggested that the application of biochar has a beneficial effect on the plant growth and pollutants removal, yet it is not suitable for food crops in contaminated land because pollutants might enter the food chain. In regard to the prospect of enhancing plant yields in the field, the influencing factors include pyrolysis feedstock type, genetic composition of the crop being examined, and specific environmental facets of field location. Biochar boosts crops growth by preventing soil nutrients from loss and improving soil environment and microbial communities. Specifically, biochar is often used as a carrier of fertilizer in the soil to slow the release fertilizer and reduce the fertilizer loss, so it is favourable to improve the utilization rate of fertilizer. Furthermore, biochar itself contains a certain amount of mineral nutrients (P, K, Ca, Mg, N), which can directly supply nutrients for crops. The pore structure of biochar provides a good habitat environment for soil microorganisms, which may promote crop growth and increase yields. For example, peanut hull biochar can improve the plant growth, and vital factors are enhancing soil microbial properties and enzyme activity. In order to promote the agricultural production, biochar application can be an emerging trend in the future.

Conclusion

Biochar is a versatile and highly beneficial material with significant potential for improving soil fertility, mitigating environmental issues, and enhancing agricultural productivity. Its unique properties, such as high carbon content, large surface area, and stable structure, make it an effective tool for carbon sequestration, soil remediation, and nutrient retention. The benefits of biochar vary depending on the feedstock and production methods, allowing for tailored applications to address specific soil and environmental challenges. When incorporated into soil, biochar can enhance soil fertility by improving pH levels, increasing cation exchange capacity (CEC), and boosting microbial activity. It also helps to retain nutrients, reduce erosion, and improve water retention, all of which contribute to healthier plant growth and increased agricultural yields. Additionally, biochar can reduce the need for chemical fertilizers, thereby lowering carbon emissions associated with fertilizer production and application.

Overall, biochar offers a sustainable solution for improving soil health and addressing environmental concerns, making it a valuable tool for sustainable agriculture and environmental management. Its diverse applications and benefits underscore its importance in modern agricultural practices and environmental conservation efforts.

References

Aller, M.F., 2016. Biochar properties: Transport, fate, and impact. *Critical Reviews in Environmental Science and Technology*, *46*(14-15), pp.1183-1296.

Chun, Y., Lee, S.K., Yoo, H.Y. and Kim, S.W., 2021. Recent advancements in biochar production according to feedstock classification, pyrolysis conditions, and applications: A review. *BioResources*, *16*(3), p.6512.

Gul, S., Whalen, J.K., Thomas, B.W., Sachdeva, V. and Deng, H., 2015. Physico-chemical properties and microbial responses in biochar-amended soils: mechanisms and future directions. *Agriculture, ecosystems & environment*, *206*, pp.46-59.

Jien, S.H., 2019. Physical characteristics of biochars and their effects on soil physical properties. In *Biochar from biomass and waste* (pp. 21-35). Elsevier.

Jindo, K., Mizumoto, H., Sawada, Y., Sanchez-Monedero, M.A. and Sonoki, T., 2014. Physical and chemical characterization of biochars derived from different agricultural residues. *Biogeosciences*, *11*(23), pp.6613-6621.

Kookana, R.S., Sarmah, A.K., Van Zwieten, L., Krull, E. and Singh, B., 2011. Biochar application to soil: agronomic and environmental benefits and unintended consequences. *Advances in agronomy*, *112*, pp.103-143.

Laird, D., Fleming, P., Wang, B., Horton, R. and Karlen, D., 2010. Biochar impact on nutrient leaching from a Midwestern agricultural soil. *Geoderma*, *158*(3-4), pp.436-442.

Lehmann, J., Rillig, M.C., Thies, J., Masiello, C.A., Hockaday, W.C. and Crowley, D., 2011. Biochar effects on soil biota–a review. *Soil biology and biochemistry*, *43*(9), pp.1812-1836.

Sohi, S.P., Krull, E., Lopez-Capel, E. and Bol, R., 2010. A review of biochar and its use and function in soil. *Advances in agronomy*, *105*, pp.47-82.

Spokas, K.A., Cantrell, K.B., Novak, J.M., Archer, D.W., Ippolito, J.A., Collins, H.P., Boateng, A.A., Lima, I.M., Lamb, M.C., McAloon, A.J. and Lentz, R.D., 2012. Biochar: a synthesis of its agronomic impact beyond carbon sequestration. *Journal of environmental quality*, *41*(4), pp.973-989.

Wang, J. and Wang, S., 2019. Preparation, modification and environmental application of biochar: A review. *Journal of Cleaner Production*, *227*, pp.1002-1022.

Xu, G., Lv, Y., Sun, J., Shao, H. and Wei, L., 2012. Recent advances in biochar applications in agricultural soils: benefits and environmental implications. *CLEAN–Soil, Air, Water*, *40*(10), pp.1093-1098.

Zhang, C., Liu, L., Zhao, M., Rong, H. and Xu, Y., 2018. The environmental characteristics and applications of biochar. *Environmental Science and Pollution Research*, *25*, pp.21525-21534.

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