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Effect of biochar on soil properties and crop growth

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Abstract
A potential soil amendment to enhance soil characteristics and crop production is biochar. Biochar boosts soil fertility by enhancing the structure of soil, expanding availability of nutrients, along with expanded water retention. Additionally, it may adjust soil pH and enhance the soil's ability for cation exchange, both of which are beneficial for crop growth. Furthermore, biochar has been linked to increased agricultural productivity, leading to improved plant development and higher yields. However, the used biochar type, its rate of application, type of soil being used and crop species can have specific effects on biochar which can vary because of these factors. Utilizing biochar more effectively across various soil types and cropping systems will require further research and field testing. It provides a sustainable way to enhance soil quality and increase agricultural production.

Keywords: Biochar, crop production, soil fertility, pyrolyzed carbon

Introduction

Soil degradation, which encompasses diminished fertility, alterations in soil pH, reduced organic matter, erosion, and pollution, can stem from intensive agricultural practices. This degradation is exacerbated by the loss or depletion of crucial components such as soil organic carbon, which compromises soil structure. Consequently, the restoration of degraded soils necessitates the development of sustainable soil management techniques. An abundance of organic and inorganic waste, including residues from agriculture, forest debris, waste from industry, and solid waste from municipality, is created in substantial quantities. Unfortunately, a majority of these waste materials are incinerated or discarded in fields, leading to air, land, and water pollution (Rauf *et al*, 2008; Gabhaneet *et al*, 2016) [1, 2]. Various studies have shown that composting all the material waste has been proposed as a promising policy. However, due to its slow rate of decomposition, composting is not widely considered to be an attractive option. Furthermore, the use of compost and manure can lead to increased emissions of methane and ammonia, which commit to global warming. In contrast, the biochar application to soil has garnered increased awareness in recent years because of its dual benefits of mitigating changing climate and improved quality of soil. Biochar, a persistent carbon-rich substance, which is produced through a thermochemical process between 350 °C and 600 °C temperatures in an oxygen-free or low- oxygen environment. Initially, biochar was considered primarily as a material for water purification and an energy source. The chemical composition and functional groups, as well as the physical characteristics such as area of surface, porosity, along with surface shape of biochar, rendering effective as an adsorption material for eliminating contaminants from water-based substances. This naturally occurring resource is also highly beneficial for regulating soil fertility. For instance, nutrient-rich biochar serves as a slow-release fertilizer it had been shown in multiple studies, enhancing soil fertility (Schmidt *et al.*, 2015) [4]. Production of biochar is from a variety of stocking feeds with pH levels ranging from 8.2 to 13.0. These feedstocks have total carbon contents ranging from 33.0% to 82.4% and nitrogen contents between 0.18% and 2.0%, with a carbon-to- nitrogen ratio of 19:1 to 221:1. The temperature at which biochar is burned impacts the preservation of nutrients. Nitrogen is preserved at 200 °C, while phosphorus and potassium are retained at temperatures between 700 °C and 800 °C, and sulphur at 375 °C. These nutrients exhibit changes in the temperature at which they evaporate. The produced biochar at a higher temperature of approximately 800 °C exhibited elevated pH, content of salt, and extort able $NO3^-$. Conversely, biochar produced at a lesser temperature of 350 °C showed higher levels of evokable $NH4^+$ and phenols (DeLuca *et al.* 2019) [5].

Biochar is a beneficial addition for rehabilitating acidic soils due to its composition of calcium and magnesium. Biochar is derived from burned residues, which have a longer period of residence than non-burned wastes. It also increases soil fertility by altering the characteristics of soil due to physical, chemical, and biological conditions. Adding biochar can increase food yields, heavy metals can be removed from the soil, and increased fertility of soil.

However, studies have shown that applications of biochar, such as surface application and soil incorporation, can have adverse effects under certain conditions. According to (Li *et al*., 2020) applying biochar to the surface combined with nitrogenous fertilizers is a useful tactic for lowering nitrogen (N) losses. The feedstock, content, and kind of soil that the biochar is to be put to all determine the extremely variable application rate of biochar. In the field trials, biochar weighing from 5 and 50 t ha-1 has been used; application rates are not specifically advised. It has been observed that field crops are treated with biochar at a dose of 1 percent by weight or less. Increased applications of biochar to soil can enhance carbon storage, but they may also limit N availability and widen the C:N ratio (Lehmann *et al*., 2007) [6] which might reduce crop production. larger dosages of biochar applied to soils that contain a lot of nitrogen and soils that are planted with legumes or use a system based on legume farming have produced larger earnings.

Biochar effect on physical properties of soil

Soil classification to be treated with biochar and the biochar itself will determine what amount of features of soil changes. Applying biochar with soil affects its wettability, infiltration of water, water retention, aggregation, and stability; these effects assist prevent erosion, lessen drought and loss of nutrients, and enhance the quality of groundwater.

Table 1: Types of biochar and their impact

S. No.	Biochar material	Impact	References
1	Hard wood charcoal	Increase soil moisture retention up to 11 to 18% in sandy and clayey soil	Tryon., (1948) [8]
2	Biochar from green waste	Increase fertilizer use efficiency up to 10% to 30%	Gaunt and Cowie (2009) [9]
3	Tobacco stalk biochar	Increase soil pH	Bindu *et al.*, (2016) [10]
4	Oil palm biochar	Increase potassium level in soil	Bindu *et al.*, (2020) [11]
5	Plant biomass biochar	Increase nitrogen fixation in soil	Mia *et al*., (2014) [12]

Bulk density and porosity

Biochar usage improved the soils' porosity, which led to a decrease (McEligott *et al.* 2011) [14]. The amount of biochar added to the cement causes a corresponding increase in the soil's overall porosity.

According to (Masulili *et al.,* 2010) [13], applying husk of rice in biochar resulted into a decrease in penetration resistance an increase overall pores, and an increase in accessible water. Applying biochar increases the soil's overall porosity, which lowers the huge amount of the soil and raised infiltration rate. The other properties(physical, chemical, and biological) of the soil—such as its ability to hold water, aggregation, texture, and structure—benefit from this drop in bulk density.

Soil texture and structure

The use of biochar transforms platy soil into granular/crumb formations that are very beneficial to crops. Remarkably soil quality improved by applying biochar, yet this impact was shown to be transient (Aslam *et al.,* 2014) [15]. The biochar application to soil may provide a route to an improvement in its physical properties due to many factors, including high porosity, adsorptive nature, availability of habitat of microbial, and overall organic content of carbon.

Soil erosion and water Runoff

Applying biochar increased water absorption, decreased water flow, and hence decreased soil particle loss (Sun *et al*., 2018) [16]. The expanded mean weight of soil fragments feasibly be the cause of this decreased soil loss. The applicability of biochar on sandy soils caused decrease in the diffusion distance horizontally of wetting front's, whereas the wetting front's vertical diffusion distance first decreased before increasing. When at 620 °C only 2% of biochar obtained from combined wood sifting was applied to non-calcareous loamy sand, the rate of in filtration increased by at least 1.7 times, while the limestone loamy soils had no discernible impact on this use of biochar. In contrast, other report less water ingrass because the biochar is hydrophobic. (Jien and wang (2013) [17] discovered a 50% reduction in soil loss. There were also observed inconsistent outcomes regarding the impact of biochar upon soil drainage. Higher rates of the use of biochar caused silty loam loess erosion to increase, but erosion decreased when larger-sized particles of biochar were applied. Various grain sizes of biochar are required for various kinds of soil to lessen water flow and damage (Sriphrom *et al*., 2020) [18]. When used in conjunction with various techniques of wetting and drying in the field, the biochar obtained by slow pyrolysis of the mangroves tree (Rhizophora apiculate) lowered water irrigation use of crop of rice with12.7%.

Soil chemical properties Soil organic Carbon

Because biochar has a high proportion of resistant carbon, adding it to the soil increased its organic carbon content. Shenbagavali and Mahimaa Raja (2012) discovered a 33%-35% greater SOC content upon using varying quantities of biochar, which lends support to this. The combination of carbon in biochar, microbes, rhizosphere breakdown, and root exudates causes the rise in SOC with biochar addition. The C oxidized in millimoles was decreased by applying biochar made from maize stover, which has a inflated ash concentration along with lower volatile matter.

Soil pH

Soil pH has an outstanding impact by the applicability of biochar; the alkaline biochar creation (leachates pH >7.0) results from progressive pyrolysis temperatures, lesser heating rates, and larger residence times, while creation of acidic biochar (leachates pH <7.0) results due to lower temperatures, higher heating rates, and shorter residence times. There is a liming effect on soil acids due to Biochar (Yuan *et al.*, 2013) [19]. The pH of the soil rises as a result of the alkaline metal oxides, hydroxides, which and carbonates found in the biochar. The H+ ions from the solution of soil are bound by negatively charged functional molecules such as carboxyl, hydroxyl, and phenolic groups; this reduces the activity of the H+ ions and raises the soil pH. On other hand (Zhang *et al.*, 2019) [20] discovered a drop in pH in alkaline soils, which may be because oxidizing biochar produces acids. The pH of alkaline soils was shown to be decreased by acidic chemicals formed at the time of breakdown of soil organic matter. The concentrations of NaHCO3 and Na2CO3 in alkaline soil were changed to Ca (HCO3)2 and CaCO3. The biochar inclusion raised the limestone soil pH as well. Nevertheless, in calcareous soils, the use of acidic biochar produced by gradual pyrolysis and activation with steam lowered the soil pH by 0.2-0.4 units. The soils' capacity to function as a buffer stopped the significant changes in soil reactivity, undoubtedly at greater application biochar rate. Soil pH was elevated above 8.0 by applying alkaline biochar which came from poultry litter, which reduced the nutrients amount available to the plants. Applying biochar made from water hyacinth increased the pH of the soil under saltwater stress conditions, and the rise was directly correlated with the amount of biochar used.

Soil nutrients

Absorb and binding are accelerated in soil with the biochar combination. This halts leakage of nutrients. Because biochar has adverse charge along with a larger surface area than other varieties, it is better equipped to hold on to exchangeable sorts of cations. This maintains the chemicals and nutrients in soil, ensuring extended food yields along optimizing usage with fertilizer. It is feasible to regulate the supply of chemical minerals to the surroundings and the harm they bring to aquatic ecosystems because biochar prevents nutrients from escaping. Additional nutrients can remain in the soil and synthetics used outside of farming can be reduced by halting the losses. The composition of nutrients in biochar varies greatly and is determined by the kind of material, pyrolysis temperature, dwell duration, and burning rate. Functional groups found in biochar include hydroxyl, acidic, ketone, and lactone groups, which cling securely to reduce losses along with ions nutrients. Many research has demonstrated that fertilizers based on biochar are more effective at using nutrients, which supports this. Biochar improves the soil and reduces the demand for fertilizer, although it is not a fertilizer. Research from (Suppadit *et al*., 2012) found that addition of 15% w/w biochar altered production of nuts. The very porous biochar character, who accelerated nutrients lack along with water among the soil, had a limiting impact on the excessive use of biochar. Experimentation is therefore mandatory to consider how much biochar will be appropriate for the ground and crop. It was discovered that the biochar results on crop enlargement along nutrient availability varies depending upon chemical composition based on the biochar, the amount applied, the pH based on soil, the condition of nutrients in the soil, and the microbial interactions with the biochar. The macro and micronutrient contributions from biochar are substantial. We refer to them as slow-release fertilizers. utilizer, according to Lehmann (2007) [6].

Biological Properties of soil Population of microbes

Applications of biochar increase microbial activity by altering the physio-chemical properties of the soil, detoxifying chemical compounds on the charcoal, and offering a haven for smaller organisms. The hydrophobic nature of the outermost layer of biochar determines bacteria attraction. The right amounts of fertilizers combined with biochar enhance the microbial population, leading to the release nutrients (chemical characteristics). (Warnock *et al*., 2007) Reports state that soil bacteria use the macropores bigger compared to 200 nm like an idle home. The soil microorganisms that live in the spaces in the biochar are protected from other predator micro arthropods in the soil by these holes. The micro in addition to holes based on biochar hold water as well as other dissolved substances which are essential for microbial metabolism. The biochar increased surface area promoted microbial colonization. Because of its black color, biochar can absorb more heat, which speeds up microbial development and enzyme activity. Because biochar is alkaline, gram-positive soil microbes were more likely to flourish on it than gram-negative bacteria. As biochar ages, fungal growth is promoted and its pH falls. noticed limited microbial colonization after applying biochar to the soils; this might be because biochar has a lower nutrient content than bulk soil and a greater sorption of smaller molecular weight compounds. After incubation for four weeks, the introduction of the pine wood biochar-bacterial combination (the Enterobacter cloacae UW5 strain) to soils from sandy loams resulted in a 16% increase in bacterial population density.

Enzyme population

Enzymes are substances secreted with the help of roots from soil or soil microbes that control the bioavailability of nutrients. The addition of biochar has similar effects on enzymatic activity as it does on the microbial feedback, including campaigns, plenty, and community composition. (Lammirato *et al.*, 2011) Enzymatic campaigns can be increased or decreased depending on how effectively the substrate is adhered to and enzymes stick to the groups of function in the biochar. In contrast, many studies revealed that biochar positively affected soil enzymes. The increase in enzyme function with the use of biochar was shown to proceeding by enhanced organic matter surrounded by soil, carbon microbial biomass, or nitrogen pools, which can be used as organic building blocks in contemplation to these enzymes. The utilization of rice husk biochar at 12tha-1 outstandingly increased the levels of soil urease, phosphate alkaline enzyme, catalase, and invertase. Soil invertase performance was firmly associated along available nitrogen, phosphorus, as well as organic carbon in soil levels. (Shahzad *et al.*, 2014) reported the use of biochar increased phosphatase activity, a sign of more bioavailable phosphorus. The enzyme activity of urease and oxidase were shown to be greatly enhanced by the inclusion of biochar made from almond shells. Enzyme activity and organic matter in the soil do not appear to be correlated, per (Jing *et al.*, 2020) [7]. The urease activity showed a positive correlation with available phosphorus and nitrogen, but the invertase activity showed a correlation with both NH4+-N and NO3-N. These enzymes are released by the plants' increased root growth, which may account for the increased enzymatic activity observed with the inclusion of biochar. The introduction of cold-temperature biochar at 350 °C enhanced dehydrogenase performance by 73%, whereas high temperature biochar (700 °C) caused a 47% decrease in dehydrogenase performance in the treated soil.

Microbial Biomass

Adding biochar has a remarkable effect upon the amount of carbon in the microbial biomass. (Rutigliano *et al.*, 2011) discovered that microbial population in soils analyzed with biochar had not changed. Similarly, it was discovered that while biochar treatments improved MBC after a year, MBC (microbial biomass charcoal) did not alter during a brief (20-30 day) timeframe. Applying high-temperature wood biochar (≥600 °C) generated with eucalyptus reduction to MBC in sandy soil by 28%. However, adding biochar manufactured from alder wood heated to 700 °C boosted MBC in sandy soils with loam by 29%, according to research by (Ameloot *et al.*, 2013). discovered that clay loam soils enriched with 700 °C-produced biochar had greater MBC. The use of organic alterations in combination with biochar is required to neutralize the temporary decline in MBC.

Effect of Biochar on crop yield

Applying biochar enhances the following characteristics such as physical, biological and chemical of the soil, which increases crop yield. The computable effect of biochar on agricultural yield. Crop yield, root weight, and seed germination were all enhanced using biochar. Applying biochar at higher doses with amalgamation with chemical-based fertilizers (NPK) boosted agricultural output. In acidic soils (pH less than 5.2), the use of biochar increases the yield of beans along with carrots. (Lehmann *et al.*,2006) Crop yields in humid tropical settings have been observed to increase with the application of biochar as much as 140 t ha-1 on heavily worn soils; however, it was not suitable for all conditions. (Rondon *et al*. 2014) Biochar insertion to soybeans was demonstrated increase biomass production up to 60 t ha-1; nevertheless, at the time the dose was expanded to Ninety t ha-1, it equaled the valuation of the control plots.

Table 2: Crop yield effect due to biochar

S. No.	Crop	Biochar made of different materials	Effect	References
1.	Rice	Rice straw	Increase rice yield	Yeng *et al.*, (2019) [20]
2.	Tomato	Eucalyptus globules	No effect on crop yield	Nzanza *et al.*, (2012) [21]
3.	Cucumber	Litchi branch	Improves crop yield	Jiang *et al.*, (2020) [7]
4.	Onion	Softwood	Neutral effect on crop yield	Gao *et al.*, (2020) [22]
5.	Radish	Rice husk	Dry matter increased	Nabavinia *et al.*, (2015) [23]
6.	Tobacco	Rice straw	Increase agronomic trait and biomass	Jiayu *et al.*, (2021) [24]
7.	Wood	Strawberry	Increase root biomass	Sumyya (2022)

Conclusion

It has been demonstrated that biochar enhances soil properties and agricultural yield. Biochar can improve soil fertility by improving soil structure, availability of nutrients, and water retention. Furthermore, biochar may increase the soil's capacity for cation exchange, which would increase plant availability and retention of nutrients. Moreover, biochar may increase soil pH and decrease soil acidity, each of which are advantageous to crop growth. Increases in yield in agricultural output have been associated with the usage of biochar. The enhanced conditions for soil that biochar produces, such as improved nutrient availability with retention of water, lead to better growth of plants and higher yields. The specific effects of biochar on ground and yields of crops, however, may vary based on a number of factors, such as the sort of biochar used, the pace of application, the kind of soil, and the plant species. When all is said and done, biochar appears to be a promising soil addition with benefits for ecologically friendly farming. More research and clinical trials are needed to determine how best to apply biochar for different soil types and farming systems to optimize its beneficial impact on soil properties along with yield of crop.

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