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Review on Effect of Biochar Application as Soil Amendment on Soil Fertility, Some Soil Physical, Biological Properties and Crop Production Improvements

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Abstract

Application of organic amendments plays a major role in improving the productivity in strongly weathered soils; organic amendments not only help as a reservoir of plant nutrients but also increase the soils nutrient retention capacity, thus help in keeping applied nutrients in the main root zone of crops. Among organic amendments biochar is a charcoal-like material that produced from pyrolysis of biomass at high-temperature with limited or no-supply of oxygen. It can be derived from a wide range of raw materials such as organic waste, feedstock like wood chips, crop residues, animal manure, sewage sludge, and microalgae biomass. Application of biochar to agricultural soils to improve plant growth by improving the physical and chemical characteristics of the soil i.e. cation exchange capacity, bulk density, improve the retention of nutrients and moisture in the soil, water holding capacity and permeability as well as biological properties, all contributing to an increased crop productivity. Moreover, due to the ability of biochar to persist in the soil over a long period of time as it is recalcitrant to decomposition, it can provide desirable benefits to crops over several seasons.

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Introduction

Application of organic amendments plays a major role in improving the productivity in strongly weathered tropical soils (Steiner *et al.*, 2007). Organic amendments not only help as a reservoir of plant nutrients such as nitrogen (N), phosphorus (P) and Sulphur (S), but also increase the soils' nutrient retention capacity, thus help in keeping applied nutrients in the main root zone of annual crops. According to Backer *et al.*, (2016) application of organic amendments increases the soil organic matter content and subsequently increases the soil organic carbon (C) pool. Furthermore application of organic amendment in long term basis to the soil help in improving several soil parameters like organic carbon, aggregate stability and crop yield, in contrast to the application of chemical fertilizers (Cheng *et al.*, 2019). Moreover organic amendments also increase soil carbon sequestration and play a decisive role in mitigating the adverse effect of climate change (Liu *et al.*, 2014; Liu *et al.*, 2019). Sukartono *et al.*, (2011) reported that commonly used organic soil amendments, such as animal manure, compost and green manures, decompose rapidly in hot and humid tropical environments, thus requiring large quantities or repeated applications to maintain long-term soil fertility.

Application of organic material having high recalcitrant carbonor high C/N ratio is an option value investigating, as these decompose slowly and therefore are retained in the soil for a long period of time (Kimetu *et al.*, 2008). Once applied, these amendments can help maintain the organic carbon level in soils and improve soil fertility. Biochar is one such organic soil amendment, which is resistant to decomposition and degradation due to condensed aromatic structures of its compounds (Lehmann, 2007).

Biochar a solid carbonaceous material produced by pyrolysis in an oxygen-limited environment has attracted increasing attention in recent decades as a way of mitigating climate change by sequestering carbon in soil with the co-benefits of waste management (Woolf *et al.*, 2010). The use of biochar for soil amendment was inspired by the *terra preta* soils in the Amazon that have been developed through the continuous addition of charcoal and organic waste materials (Lehmann *et al.*, 2011). Many studies demonstrated the importance of biochar in improving soil functions such as soil fertility (Kätterer *et al.*, 2019), soil microbial activity and diversity (Lehmann *et al.*, 2011), mitigating greenhouse gas emissions (Jeffery *et al.*, 2016), improving the immobilization and adsorption of pollutants (Zhelezova *et al.*, 2017) and significant effect on soil fertility by altering the chemical, biological and physical characteristics of the soil (Awad *et al.*, 2018). Consequently, there is considerable interest in biochar application on soil for long-term carbon sequestration and soil fertility management. The objectives of this review are 1) to provide a condensed overview of biochar, the effects of biochar application as soil amendments on soil properties, soil fertility and crop productivity improvements.

Over View of Biochar

Biochar is a carbon-rich organic material, an organic amendment, and a by-product derived from biomass (such as wood, manure, or leaves) by pyrolysis under high-temperature and low- oxygen conditions (Wang *et al.*, 2019). Although the concept of biochar is not new, the term 'biochar' was coined recently (Neves *et al.*, 2004). Several evidences indicate towards the usage of biochar in the fields from the time immemorial, for example the Amazon Basin. Biochar can most easily be described as finely ground charcoal. However, that is not the whole story and there are a number of key factors which make biochar distinctly different from the traditional charcoal we use for our barbeques. Biochar is applied back onto the land rather than being burned; Biochar is produced and used in the form of small granules or a powder rather than big lumps; it can be produced from a wide range of different materials, not just wood. Biochar has been reported to be widely considered as soil amendment. It has composed of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), Sulphur (S) and ash in different proportions. Biochar mainly used to improve soil nutrient content and to sequester carbon from the environment (Lehmann 2009). The properties of biochar closely depend on the temperature of the pyrolysis process (Park *et al.*, 2013). An increase in the temperature of pyrolysis leads to greater carbonification of the feedstock resulting in higher carbon content and a decrease in the contents of hydrogen and oxygen (Uchimiya *et al.*, 2011).

It's highly porous structure makes it attractive option for soil amendment as it improves water holding capacity of the soil by increasing the total surface area of the soil (Srinivasarao *et al.*, 2013). Among organic amendments, biochar has adsorptive and unique properties, including the presence of various functional groups, large surface area, high porous structure, surface pH and cation exchange capacity, low density, high carbon content and ability to retain additional carbon (Nie *et al.*, 2018), thus has been widely used in soil bioremediation of different heavy metals (Huang *et al.*, 2017; Yoo *et al.*, 2018). From the agricultural point of view, the application of carbonization products for soil amelioration seems to be beneficial because the treatment improves the conditions for plant growth, leading to a better yield (Macdonald *et al.*, 2014). Furthermore, due to the rapid effects and relatively low costs of such treatment, biochars are more and more frequently used in processes of soil remediation and conservation (Beesley *et al.*, 2011).

Soil Fertility Improvements

Depletion in soil organic matter and soil nutrients, decline in agricultural productivity and changes in climate due to anthropogenic activities are posing great threats to the sustainability of agricultural production in the tropical regions (Pender *et al.*, 2009). Chemical fertilizers have undoubtedly played a vital role towards increasing the agricultural productivity over past half century (Gruhn *et al.*, 2000). Declining soil quality and loss in per capita land area demanded the increase in inorganic fertilizer use. However, the use of chemical or inorganic fertilizers for improving the agricultural yield and soil fertility is not a sustainable approach; rather, it has been widely took in that the excessive use of inorganic fertilizers mainly nitrogen, has the ability to deteriorate soil environment and can also lead to the mineralization of organic matter (Liu *et al.*, 2010). So it is becoming important to restore deteriorated agricultural land by using organic fertilizers.

Among organic fertilizers, the use of biochar is quite a novel approach having potential benefits to both environment and agriculture. The addition of biochar improves degraded and low fertility soils, and thus improves crop production (El-Naggara *et al.,* 2019). Biochar can act as a soil conditioner or soil amendment to improve the soil quality, enhance plant growth by supplying nutrients, and retain nutrients. Biochar supplied either directly by providing nutrients to plants or indirectly by improving soil environment, with consequent improvement of fertilizer use efficiency. Various study results have shown that biochar application can enhance soil nutrients (Sohi *et al.,* 2010), improve plant growth and crop yields (Major *et al.,* 2010), and limit greenhouse gas emissions from the soil (Liu *et al.,* 2014).

Chan and Xu (2009) reported that biochar increase nutrient uptake by plants, and as consequence their productivity for its ability to retain nutrients in the soil and reduce leaching losses. Various evidences and studies showed that the utilization of biochar can be extremely useful for the improvement of Soil organic Carbon (Glaser *et al.,* 2002) capacity of water holding (Abel *et al.,* 2013) stimulating soil microbes, increasing the microbial activity and biomass (Thies and Rillig, 2009), decreasing in needs and leaching of fertilizers, availability and retention of nutrients, soil aeration (Laird, 2008), bettering the growth and yield of crop growth. Biochar, being used as soil amendment have a significant effect on soil fertility by altering the chemical, biological and physical characteristics of the soil (Awad *et al.,* 2018).

Biochar impact as soil amendment enhances soil quality and plant growth with increased crop yield. When applied to land, biochar is not only a carbon sink, but can act as a soil improver by increasing the water and nutrient-holding capacity of the soil (Mukherjee and Lal, 2013). Moreover, Biochar could be used as an alternative liming material in improving acid soil fertility and productivity (Nurhidayati and Mariati, 2014). Preventing the loss of water and nutrient is one of the environmental benefits of biochar application to the soil. Commonly, the carbon content increased with increasing pyrolysis temperature from 300 to 800^{0}C. According to Rajkovich *et al.,* (2012) the content of ash in biochars ranged from 0.35 to 59.05 %, which were rich in available nutrients, especially cationic elements, such as K (0–560 mmol kg^{-1}), Ca (3–1210 mmol kg^{-1}), Mg (0–325 mmol kg^{-1}), and Na (0–413 mmol kg^{-1}). Similarly, Yuan *et al.,* (2011) stated that the content of soluble base cations (K^+, Ca^{2+}, Mg^{2+}, and Na^+) ranged from 48 to 330 cmol kg^{-1}. Moreover, ash content could increase soil pH which may determine cation exchange capacity of various charged soils and nutrient availability (Mengel and Kirkby, 2001).

Olakayode *et al.,* (2019) reported that biochar are more beneficial to adequately improved water movement in the soil. Yang *et al.,* (2018) stated that biochar have a strong attraction for organic contaminants, therefore it helps to prevent toxic substances from contaminating the environment. Many studies have shown that biochar is a useful resource to improve the physicochemical properties of soil, effectively maintain SOM levels, and increase fertilizer-use efficiency and increase crop production, particularly for long-term cultivated soils in subtropical and tropical regions (Van Zwieten *et al.,* 2010). The beneficial effects of biochar on plant productivity and soil microbial population are related to the improvement of specific surface area, cation exchange capacity, bulk density, pH, water, and nutrients within the soil matrix (Thies and Rillig, 2009).

Role of Biochar on Soil Physical Properties Improvement

Soil physical properties of soil have direct influence on soil productivity and crop production; they determine soil water holding capacity, aeration and strength which affect root activity (Rattan *et al.,* 2015). Soil having good structure, porosity, hydraulic conductivity, bulk density and strength provide good medium for growth to beneficial microorganisms, better nutrient and water movement into the soil profile, higher nutrient and water retention and more root growth ultimately provide higher yield as compared to degraded soil having poor physical properties (Abdallah *et al.,* 1998). However soil physical properties may be treated by different agricultural activities. Soil organic matter is one of the main factors affecting physical properties of soil. Organic matter improves soil structure by increasing soil aggregation, increases soil porosity due to its high porous nature, boast up nutrient and water retention due to its high adsorption capacity and high surface area all these results in better root growth and crop yield (Aslam *et al.,* 2014). Among agricultural soil amendment that can enhance crop productivity and soil sustainability is biochar. Biochar can greatly influence various soil properties due to the high specific surface area of biochar (Lehmann and Joseph, 2009). Amending soil with biochar increases carbon storage and can lead to changes in soil physical factors such as bulk density and water holding capacity (Lehmann and Joseph, 2015; Noyce *et al.*, 2016). Sun and Lu (2014) reported that significant changes in soil aggregate stability, water retention, and pore size distribution were observed after addition of biochar to a clayey soil. According to Mukherjee *et al.*, (2013) biochar application decreased the soil bulk density because porosity of biochar is very high and when it used in soil it significantly decrease bulk density by increasing the pore volume.

Uzoma *et al.*, (2011) stated that Biochar application boast up the available water content of the soil up to 97 percent and saturated water contents 56 percent. Laird *et al.*, (2010) described that the biochar amended soil retained 15 % more moisture contents as compared controlled treatment.

Evidence suggests that biochar application into soil may increase the overall net soil surface area (Chan *et al.*, 2007) and consequently, may improve soil water and nutrient retention (Downie *et al.*, 2009) and soil aeration, particularly in fine-textured soils. Biochar has been found to alleviate soil compaction by decreasing bulk density, which increases porosity and enhances favorable soil processes (Akhtar *et al.*, 2014).

Soil Aggregation Improvements

Soil aggregation, largely responsible for soil structure, is fundamental for soil functioning and agricultural productivity. It has a basic unit of soil structure, which mediates many physical, chemical, and biological processes of soil and affecting soil functions and health such as soil aeration, the movement and storage of soil water, soil erodibility, and carbon sequestration (Shi *et al.*, 2017).

A soil which is well aggregated has a good structure and as a result provide good medium for nutrient and water movement into the soil and uptake by plants (Borselli *et al.*, 1996). According to Blanda *et al.*, (2014) soil aggregates control the dynamics of soil organic matter (SOM) and influence the soil´s ability to sequestrate and stabilize organic carbon.

Maintenance of a high aggregate stability in soils is desirable for sustainable land use as it is essential for the preservation of agricultural production, minimizing soil erosion and degradation, mediates air permeability, water infiltration and nutrient cycling and reducing environmental pollution (Spohn and Giani, 2011). Soil management, specifically the use of different tillage systems, affects soil aggregation directly by physical disruption of the Macro aggregates, factors (Barto *et al.*, 2010).

Among organic amendments, biochar has unique properties such as high porosity, low density, high carbon content, and the ability to retain additional carbon (Zwieten *et al.*, 2012). Biochar application to agricultural soils can improve soil properties, particularly physical properties (i.e., structure, pore size distribution, bulk density, soil porosity, aggregate stability, available holding capacity, and statured hydraulic conductivity), thereby improving the air, moisture condition in the soil and increase crop production (Lu *et al.*, 2014b; Ding *et al.*, 2016). Dorioz *et al.*, (1993) described that certain polysaccharides secreted by microorganisms also increase the adherence of soil colloidal particles, as a result provides protection to microorganisms and also prevents them from predators and desiccation. The microorganisms secrete polysaccharides which increase soil aggregation (Angers *et al.*, 1993).

Owing to high surface area and porosity of biochar, its addition to soils should influence soil structure and porosity through changing the bulk surface area, pore size distribution, and soil bulk density (Downie *et al.*, 2009; Major *et al.*, 2010). With biochar addition, the increase of the availability of soil organic matter, the water holding capacity, and the bioavailable nutrition elements can significantly enhance the microbial activities and thereby the soil aggregate formation and stability (Downie *et al.*, 2009). Glaser *et al.*, (2002) has reported that the formation of complexes of biochar with minerals, as the result of interactions between oxidized carboxylic acid groups at the surface of biochar particles, should be responsible for the improved soil aggregate stability.

Effect on Soil bulk density and porosity

In two year experiments Adekiya *et al.*, (2020) reported that application of biochar reduced bulk density and increased porosity of the soil significantly compared with the control, which is biochar reduced bulk density and increased porosity as the levels of the biochar increased with 30 t ha^{-1} biochar having the least bulk density y and highest porosity. In the first year, 30 t ha^{-1} biochar reduced bulk density by 46.3% and increased porosity by 46.5% compared with no application of biochar. The reduction in bulk density was 74.7% and increases in porosity were 65.0% in the second year. Hardie *et al.*, (2014) tested this direct effect theory in a 30-monthlong field experiment. They expected that biochar would increase plant available water in the soil through the addition of pores with a diameter of between 30 μm and 0.2 μm.

Similarly, According to Mukherjee *et al.*, (2013) biochar application decreased the soil bulk density because porosity of biochar is very high and when it used in soil it significantly decrease bulk density by increasing the pore volume. Githinji (2013) decided that by increasing the rate of biochar application bulk density was also significantly decreased. Omondi *et al.*, (2016), who reported that biochar application, can reduce bulk density by 7.6% and increase the porosity of the soil by 2 to 41%.

According to Chang *et al.*, (2021) Soil bulk density decreased, while water holding capacity and total porosity increased gradually with the increase in biochar rate and a significant positive correlation between water holding capacity and biochar application rate is observed when the biochar application rate was below 20%. According to Toková *et al.*, (2020) gradual increase in the biochar dose gradually decreased BD. However, a significant decrease ($p < 0.05$) of BD was found only when biochar was applied and re-applied at a dose of 20 t ha^{-1} when compared to control.

Role of Biochar on Soil Biological Properties Improvement

Soil biological activities are an important part of soil quality since microorganisms and their associated enzymes in soil are responsible for the breakdown of organic matter and release of nutrients (Burns *et al.*, 2013). Biochar has been shown not only to improve soil physicochemical properties but also to change soil biological properties (Lehmann *et al.*, 2006).

These changes could ameliorate soil structure, containing increasing organic/mineral complexes (aggregates) and pore spaces, enhance nutrient cycles, which include the increase of nutrient retention and immobilization, as well as the decrease of nutrient leaching (Steiner *et al.*, 2008b), thus promote plant growth (Warnock *et al.*, 2007). It may increase microbial activity, provide habitat for microorganisms and hence alter microbial mediated processes in soil (Lehmann *et al.*, 2011). Changes in microbial community composition or activity induced by biochar may affect nutrient cycles and plant growth, as well as the cycling of soil organic matter (Kuzyakov *et al.*, 2009). Biochar addition can increase soil microbial biomass, and may also affect the soil biological community composition, which in turn will affect nutrient cycling, plant growth, and greenhouse gas emission, as well as soil organic carbon mineralization (Lehmann *et al.*, 2011). It has been reported to be more effective than other organic materials in retaining and making nutrients available to plants (Li *et al.*, 2014). Its surface area and complex pore structure are habitat to bacteria and fungi which are beneficial to plant (Jin *et al.*, 2014).

Effect on Microorganism Community

Application of biochar to soils stimulates the activities of soil microorganisms that influence soil quality and plant performance. The physiochemical properties of biochar are responsible for changes in soil character including changes in pH, nutrient maintenance, and water retention, which can induce heterogeneous responses in microbial species.

This response can result in changes in microbial community structure and can consequently alter soil element cycling and function (Biederman and Harpole, 2013). There are some components in biochar, including minerals, volatile organic compounds, and free radicals (Spokas *et al.*, 2011), that can potentially influence microbial activity, reshape the soil microbial community, and change the soil enzyme activity that catalyzes various key biogeochemical processes including soil organic matter turnover and elemental cycles (e.g., N, P, and S) (Paz- Ferreiro *et al.*, 2014). Biochar can participate in soil processes such as organic matter decomposition as it takes part in the direct extracellular electron transfer between soil organic matter (or soil minerals) and microbial cells, as well as in the direct interspecific electron transfer between microbial cells (Chen *et al.*, 2014).

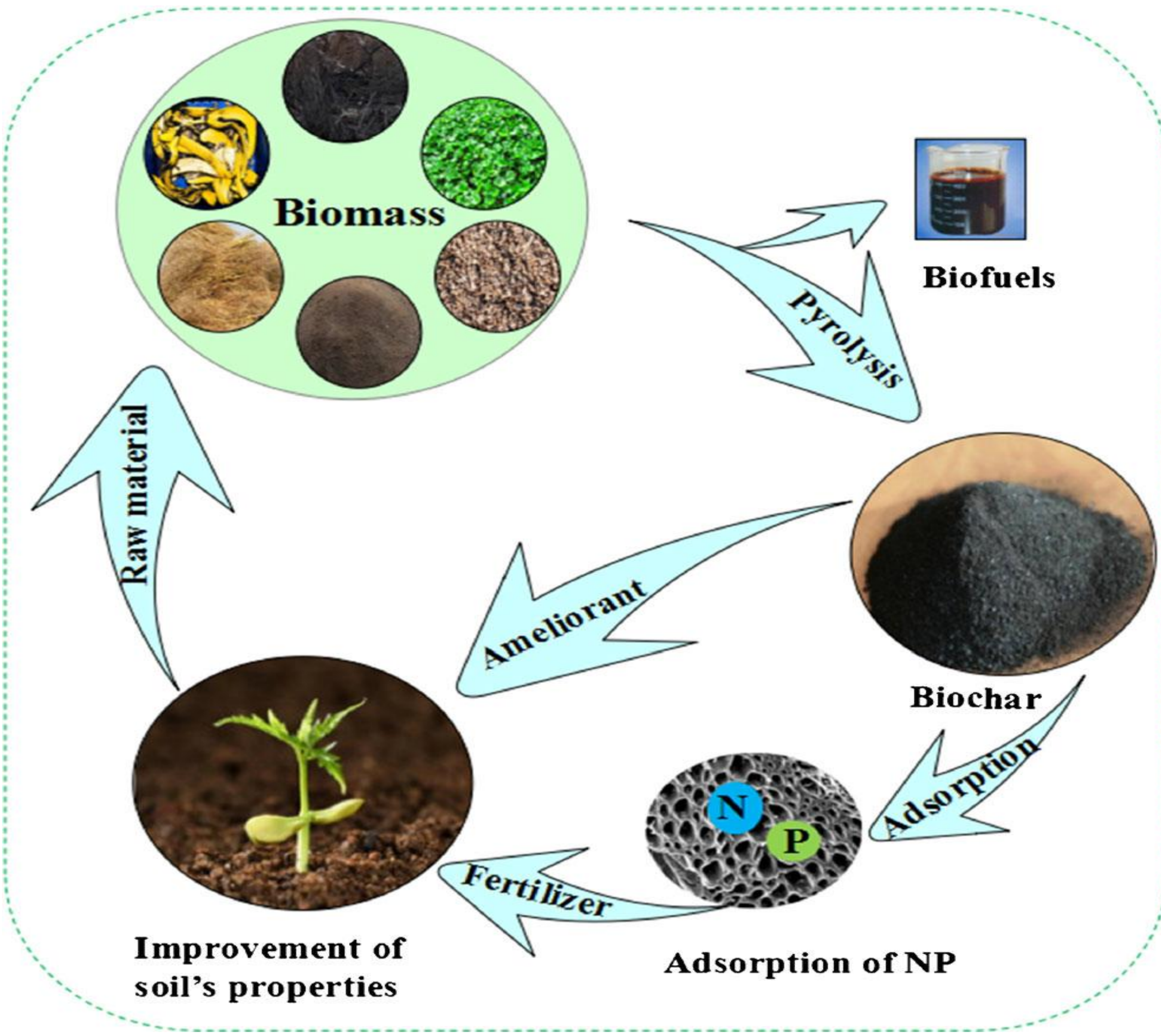
Biochar improves the biological condition of soils (Kwapinski *et al.*, 2010), increases soil microbial biomass, stimulate soil microbial activity and change microbial community in soil (Pietikainen *et al.*, 2000) by changing physicochemical properties of soils (Steiner *et al.*, 2007; Lehmann *et al.*, 2011). According to Lehmann *et al.*, (2011), biochar addition also can affect the soil biological community composition, which in turn will affect nutrient cycling, plant growth, and greenhouse gas emission, as well as soil organic carbon mineralization.

Table.1 Effects of biochar as soil amendment on some soil physical properties

Biochar rate %	Water-holding capacity (%)	Bulk density (g cm^{-3})	Total porosity (%)
0	28	1.47	45
5	34	1.21	54
10	40	1.08	60
15	46	1.02	62
20	52	0.88	67

Source: Chang *et al.*, (2021).

Fig.1 Benefits of biochar application for soil fertility management. Source: (Yang *et al.*, 2017).



A small fraction of labile carbon in biochar can be mineralized within a short period and can stimulate soil microorganism growth (Quilliam *et al.*, 2013). Biochar can provide a substrate for soil microorganisms, thereby enhancing microorganism activity (Gomez *et al.*, 2014). Biochar amendment may stimulate plant growth through enhanced microbial activity (Azeem *et al.*, 2019) and can affect microbial abundance, bacteria/ fungi ratio and community structure (Zhang *et al.*, 2018). Interactions between biochar, soil, microbes, and plant roots were known to occur within a short period after application to the soil (Lehmann and Joseph, 2009). Biochars application in the soil can affect soil microbial community structure due to their high sorption capacity

(Lehmann *et al.*, 2011), changing the soil pH as well as modification of microbial environment.

Effect on Microbial Abundance

Domene *et al.*, (2014) reported that microbial abundance could increase from 366.1 (control) to 730.5 µg C g^{-1} after an addition of 30 t ha^{-1} biochar. Similarly, (Domene *et al.*, 2015) indicated that microbial abundance increased by 5–56 % with the increase of corn stalk biochar rates (from 0 to 14 %) for the different pre incubation times (2–61 days). Some possible reasons may be responsible for the increase of microbial abundance, such as higher availability of nutrients or labile organic matter on biochar surface (Bruun *et al.*, 2012), less competition, the enhanced habitat suitability and refuge (Warnock *et al.*, 2007), the increased water retention and aeration or positive priming (Zimmerman *et al.*, 2011). Furthermore, nutrient and carbon availability can affect microbial abundance. This influence was greatly varied with the different types of biochar and the special microorganisms group. It can be considered that symbiotic relationships with biota through changing nutrient supplies were formed from the different demands of the plant.

Similar explanations may hold for the effect of carbon supply increasing by exudation or root turnover in the rhizosphere and carbon as energy sources for heterotrophic microorganisms (Lehmann *et al.*, 2011). Consequently, the influence on microbial abundance was dissimilar with the different sphere of biochar additions, including rhizosphere and bulk soil. The possible reasons were biochar-driven improvements in nutrient retention or the release of nutrient by the biochar (Lehmann *et al.*, 2011).

The pH of soils may change, after biochar additions, because of the acidity or basicity of biochar. Different living conditions will be formed for microorganisms with different pH of biochar. AciegoPietry and Brookes (2008) revealed that microbial biomass carbon increased from about 20 to 180 µg biomass C g^{-1} soil and microbial biomass ninhydrin-N increased from about 0.5 to 4.5 µg ninhydrin- N g^{-1} soil with rising pH values from 3.7 to 8.3 under otherwise identical environmental conditions, which demonstrated that the rising soil pH could increase microbial biomass. Moreover, there are different influences on different microbial abundance if pH values are changed. With the increase of pH up to values around 7, bacterial populations were possible to increase, whereas, no change in fungi abundance was observed (Rousk *et al.*, 2010). Similar to nutrient and carbon changes, the pre-existing soil pH, the direction, and magnitude of change will also largely affect the level of pH changes. Microbial abundance could be increased after microorganisms sorb to biochar surfaces, which render them less susceptible to leaching in soil.

Effect on Modification of Microbial Habitats

Biochar can modify microbial habitats by improving the soil's physical properties. Biochar porosity can decrease soil bulk density, improve soil aeration condition (Abel *et al.*, 2013), and control the transport of soil microbes in biochar amended soil (Abit *et al.*, 2012). Biochar can increase the available water content that influences nutrient accessibility to microbial cells (Abel *et al.*, 2013). Moreover, the improved water retention capacity means that there is a greater capability of the soil to hold water against dry-wet cycles in the natural environment, which can favor the maintenance of a stable microbial activity (Liang *et al.*, 2014). The pyrolysis parameters (mainly temperature, heating rate and time) and feedstock compositions (e.g., lignin and lipid concentrations) of the preparation of biochar control its porosity, carbon stability, and the surface adsorption of nutrients (Cantrell *et al.*, 2012). The role of biochar in improving soil properties and modifying microbial habitats can be dependent on the feedstock types and pyrolysis procedures used in making biochar. Biochar can be an effective liming agent to neutralize soil pH (Yuan *et al.*, 2011).

An increase of the soil pH by 0.2 - 0.3 units after biochar application can be the main factor affecting the soil microbial community, in contrast to other chemical variables in soil such as the total carbon content, total nitrogen content, electrical conductivity, and NO_3^- and NH_4^+concentrations (Nielsen *et al.*, 2014). An increase in the soil pH and a decrease in the toxicity of exchangeable Al in acidic soils with biochar amendment (Qian *et al.*, 2013) increase the bacteria abundance in the pH range from 4 to 7; the abundances of bacteria are positively correlated with soil pH (Rousk *et al.*, 2010). Fungi and bacteria have different sensitivities to soil pH and bacteria are generally more tolerant to a narrower range of pH and are more sensitive to soil pH changes than fungi are (Rousk *et al.*, 2010). As a result, there are likely to be different responses from bacteria and fungi to biochar-induced changes in soil pH, and the microbial community of fungi and bacteria may react in different ways to biochar induced changes in soil pH, which can result in an alteration of the overall microbial community structure. A pyrosequencing analysis of the soil bacterial community showed significant correlation between the soil pH and the soil bacterial community composition. Increasing the soil pH with biochar application altered the abundance, diversity, and composition of nitrifying bacteria in soil and changed soil nitrification as a consequence (Zhang *et al.,* 2017).

Influences of biochar application on crop productivity

Other than increasing soil carbon storage, the incorporation of biochar into the soil has been shown to improve soil fertility (Lehmann and Joseph, 2009). Moreover, biochar amendments can improve soil fertility by increasing soil pH (Zwieten *et al.,* 2010), soil cation exchange capacity (CEC), potassium (K) availability, and water retention, reducing nutrient leaching (Laird *et al.,* 2010) and increasing the proportion of biological nitrogen fixation. (Rondon *et al.,* 2007). As a result biochar application facilitates good environment for increment of crop productivity. Vaccari *et al.,* (2011) reported that biochar addition improved yields of different crops by up to 200% in a range of different experiments. This beneficial effect may be due to a direct addition of nutrients such as potassium (K), calcium (Ca), and magnesium (Mg), which are present in biochar, especially when nutrient rich biomass is used as feedstock (Atkinson *et al.,* 2010). Likewise Yamato *et al.,* (2006) reported that biochar applications increased maize, cowpea, and peanut yields under fertilized conditions due to increases in soil pH, cation exchange capacity (CEC), and nutrient availability.

Uzoma *et al.,* (2011) stated that 150 and 98% increases in maize grain yield at 15 and 20 t/ha biochar application, respectively, and attributed this to improvements in both soil physical and soil chemical properties. Similarly, Van Zwieten *et al.,* (2008) reported that application biochar derived from poultry litter with 10 and 50t/hak Produce 25 and 35ton cob fresh weight per hectare respectively. The improvements in plant growth and crop yields with biochar application result from the modification of soil physical, chemical, and biological properties. Jeffery *et al.,* (2011) reported 28–39% changes in plant productivity (crop yield and aboveground biomass) following biochar amendment to soils. Knoblauch *et al.,* (2021) reported that crop yield in the biochar treatments was generally substantially larger than in plots without biochar, which was fresh corn biomass yield on the fallow biochar plots during the two summer seasons (39.2–45.5 t ha^{-1}) increased significantly by 33 to 37% compared with the yields on the control plots (28.6–34.1 t ha^{-1}). Additionally, Adekiya *et al.,* (2020) reported that biochar increased the cormel yield of cocoyam significantly compared with the control. In 2017 and 2018 years, the yield of cocoyam was increased as the level of biochar increased from 0–30 t ha^{-1}, and year 2018 increased yield of cocoyam compared with 2017. Compared with 2017, there was an increase in cocoyam yield by 8.1, 7.8, and 5.5% for 10, 20, and 30 t ha^{-1} biochar, respectively, and a reduction of 13% for the control.

In most cases, biochar emerging as an efficient amendment with huge functions comprised of carbon sequester, act as soil conditioner through changing the biological and physiochemical properties of soil, improve the fertility of soil and particularly its water holding capacity, cation exchange capacity and pH, as well as mycorrhizal colonization. Biochar is an effective soil amendment; it improves soil structure and fertility, thereby enhancing crop growth and development. Biochar amendment had a strong impact on soil physical properties, such as moderating soil thermal properties, buffering soil pH, improving soil water holding capacity, and decreasing soil bulk density. Since biochar lowered soil bulk density, thereby increasing soil porosity and soil aeration, it may have positive effects on roots. This can result in increased porosity and water infiltration, and reduced the risks of water erosion. These specific effects indicate biochar's ability to add nutrients and improve nutrient use efficacy in soil that ultimately contributes toward better crop growth and improved yields.

References

Adekiya, A. O., T. M. Agbede, C. M. Aboyeji, O. Dunsin, and V. T. Simeon, "Effects of biochar and poultry manure on soil characteristics and the yield of radish," *Scientia Horticulturae,* vol. 243, pp. 457–463, 2019.

Abel, S., Peters, A., Trinks, S., Schonsky, H., Facklam, M. and Wessolek, G., 2013.Impact of biochar and hydrochar addition on water retention and water repellency of sandy soil. *Geoderma, 202,* pp.183-191.

Adekiya, A. O., Agbede, T. M., Olayanju, A., Ejue, W. S., Adekanye, T. A., Adenusi, T. T. and Ayeni, J. F., 2020. Effect of biochar on soil properties, soil loss, and cocoyam yield on a tropical sandy loam Alfisol. *The Scientific World Journal, 2020.*

Adekiya, A. O., Ejue, W. S., Olayanju, A., Dunsin, O., Aboyeji, C. M., Aremu, C., Adegbite, K. and Akinpelu, O., 2020. Different organic manure sources and NPK fertilizer on soil chemical properties, growth, yield and quality of okra. *Scientific Reports*, *10*(1), p.16083.

Atkinson, C. J., Fitzgerald, J. D. and Hipps, N. A., 2010. Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review. *Plant and soil*, *337*, pp.1-18.

Backer, R. G., Schwinghamer, T. D., Whalen, J. K., Seguin, P. and Smith, D. L., 2016. Crop yield and SOC responses to biochar application were dependent on soil texture and crop type in southern Quebec, Canada. *Journal of Plant Nutrition and Soil Science*, *179*(3), pp.399-408.

Borchard, N.; Schirrmann, M.; Cayuela, M. L.; Kammann, C.; Wrage-Mönnig, N.; Estavillo, J. M.; Fuertes-Mendizábal, T.; Sigua, G.; Spokas, K.; Ippolito, J. A.; *et al.*, Biochar, soil and land-use interactions that reduce nitrate leaching and N2O emissions: A meta-analysis. Sci. Total Environ. 2019, 651, 2354–2364.

Bruun, E. W., Ambus, P., Egsgaard, H. and Hauggaard-Nielsen, H., 2012. Effects of slow and fast pyrolysis biochar on soil C and N turnover dynamics. *Soil Biology and Biochemistry*, *46*, pp.73-79.

Cantrell, K. B., Hunt, P. G., Uchimiya, M., Novak, J. M. and Ro, K. S., 2012. Impact of pyrolysis temperature and manure source on physicochemical characteristics of biochar. *Bioresource technology*, *107*, pp.419-428.

Chan, K. Y. and Xu, Z., 2009. Biochar: nutrient properties and their enhancement. *Biochar for environmental management: science and technology*, *1*, pp.67-84.

Chang, Y., Rossi, L., Zotarelli, L., Gao, B., Shahid, M. A. and Sarkhosh, A., 2021. Biochar improves soil physical characteristics and strengthens root architecture in Muscadine grape (*Vitis rotundifolia* L.). *Chemical and Biological Technologies in Agriculture*, *8*, pp.1-11.

Domene, X., Mattana, S., Hanley, K., Enders, A. and Lehmann, J., 2014. Medium-term effects of corn biochar addition on soil biota activities and functions in a temperate soil cropped to corn. *Soil Biology and Biochemistry*, *72*, pp.152-162.

Farahani, S. S.; Asoodar, M. A.; Moghadam, B. K. Short-term impacts of biochar, tillage practices, and irrigation systems on nitrate and phosphorus concentrations in subsurface drainage water. Environ. Sci. Pollut. Res. 2020, 27, 761–771.

Githinji, L., 2014. Effect of biochar application rate on soil physical and hydraulic properties of a sandy loam. *Archives of Agronomy and Soil Science*, *60*(4), pp.457-470.

Hardie, M., Clothier, B., Bound, S., Oliver, G. and Close, D., 2014. Does biochar influence soil physical properties and soil water availability?. *Plant and soil*, *376*, pp.347-361.

Huang, D., Wang, X., Zhang, C., Zeng, G., Peng, Z., Zhou, J., Cheng, M., Wang, R., Hu, Z. and Qin, X., 2017. Sorptive removal of ionizable antibiotic sulfamethazine from aqueous solution by graphene oxide-coated biochar nanocomposites: influencing factors and mechanism. *Chemosphere*, *186*, pp.414-421.

Jeffery, S., Verheijen, F. G., van der Velde, M. and Bastos, A. C., 2011. A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. *Agriculture, ecosystems & environment*, *144*(1), pp.175-187.

Jeffery, S.; Abalos, D.; Prodana, M.; Bastos, A. C.; van Groenigen, J. W.; Hungate, B. A.; Verheijen, F. Biochar boosts tropical but not temperate crop yields. Environ. Res. Lett. 2017, 12, 053001.

Jin, H., Capareda, S., Chang, Z., Gao, J., Xu, Y. and Zhang, J., 2014. Biochar pyrolytically produced from municipal solid wastes for aqueous As (V) removal: adsorption property and its improvement with KOH activation. *Bioresource technology*, *169*, pp.622-629.

Knoblauch, C., Priyadarshani, S. R., Haefele, S. M., Schröder, N. and Pfeiffer, E. M., 2021. Impact of biochar on nutrient supply, crop yield and microbial respiration on sandy soils of northern Germany. *European Journal of Soil Science*, *72*(4), pp.1885-1901.

Kimber, L. S., Sinclair, K., Chan, K. Y., Downie, A., Boschma, S. P., Serafin, L. M. and Ayres, J. F., 2008. Biochar: potential for climate change mitigation, improved yield and soil health. *Carbon*, *27*(48), pp.190-198.

Laird, D. A., Fleming, P., Davis, D. D., Horton, R., Wang, B. and Karlen, D. L., 2010.Impact of biochar amendments on the quality of a typical Midwestern agricultural soil. *Geoderma*, *158*(3-4), pp.443-449.

Lehmann, J. and Joseph, S., 2009. Biochar for environmental management: an introduction. *Biochar for environmental management: science and technology*, *1*, pp.1-12.

Lehmann, J., Gaunt, J. and Rondon, M., 2006. Bio-char sequestration in terrestrial ecosystems–a review. *Mitigation and adaptation strategies for global change*, *11*, pp.403-427.

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.

Liu, B., 2010. Uncertain risk analysis and uncertain reliability analysis. *Journal of Uncertain Systems*, *4*(3), pp.163-170.

Liu, J.; Jiang, B.; Shen, J.; Zhu, X.; Yi, W.; Li, Y.; Wu, J. Contrasting effects of straw and straw-derived biochar applications on soil carbon accumulation and nitrogen use efficiency in double-rice cropping systems. Arg. Ecosyst. Environ. 2021, 311, 107286.

Liu, X., Li, L., Bian, R., Chen, D., Qu, J., WanjiruKibue, G., Pan, G., Zhang, X., Zheng, J. and Zheng, J., 2014.Effect of biochar amendment on soil-silicon availability and rice uptake. *Journal of Plant Nutrition and Soil Science*, *177*(1), pp.91-96.

Liu, Z., Chen, X., Jing, Y., Li, Q., Zhang, J. and Huang, Q., 2014. Effects of biochar amendment on rapeseed and sweet potato yields and water stable aggregate in upland red soil. *Catena*, *123*, pp.45-51.

Major, J., Rondon, M., Molina, D., Riha, S.J. and Lehmann, J., 2010.Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. *Plant and soil*, *333*, pp.117-128.

Mehmood, I.; Qiao, L.; Chen, H.; Tang, Q.; Woolf, D.; Fan, M. Biochar addition leads to more soil organic carbon sequestration under a maize-rice cropping system than continuous flooded rice. Agric. Ecosyst. Environ. 2020, 298, 106965

Mukherjee, A. and Zimmerman, A. R., 2013. Organic carbon and nutrient release from a range of laboratory-produced biochars and biochar–soil mixtures. *Geoderma*, *193*, pp.122-130.

Nie, C., Yang, X., Niazi, N.K., Xu, X., Wen, Y., Rinklebe, J., Ok, Y. S., Xu, S. and Wang, H., 2018. Impact of sugarcane bagasse-derived biochar on heavy metal availability and microbial activity: a field study. *Chemosphere*, *200*, pp.274-282.

Nielsen, S., Minchin, T., Kimber, S., van Zwieten, L., Gilbert, J., Munroe, P., Joseph, S. and Thomas, T., 2014. Comparative analysis of the microbial communities in agricultural soil amended with enhanced biochars or traditional fertilisers. *Agriculture, ecosystems & environment*, *191*, pp.73-82.

Omondi, M. O., Xia, X., Nahayo, A., Liu, X., Korai, P. K. and Pan, G., 2016. Quantification of biochar effects on soil hydrological properties using meta-analysis of literature data. *Geoderma*, *274*, pp.28-34.

Park, J., Hung, I., Gan, Z., Rojas, O. J., Lim, K. H. and Park, S., 2013. Activated carbon from biochar: Influence of its physicochemical properties on the sorption characteristics of phenanthrene. *Bioresource technology*, *149*, pp.383-389.

Phares, C. A.; Amoakwah, E.; Danquah, A.; Akaba, S.; Frimpong, K. A.; Mensah, T. A. Improved soil physicochemical, biological properties and net income following the application of inorganic NPK fertilizer and biochar for maize production. Acta Ecol. Sin. 2022, 42, 289–295.

Qian, T., Zhang, X., Hu, J. and Jiang, H., 2013.Effects of environmental conditions on the release of phosphorus from biochar. *Chemosphere*, *93*(9), pp.2069-2075.

Rondon, M. A., Lehmann, J., Ramírez, J. and Hurtado, M., 2007. Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with bio-char additions. *Biology and fertility of soils*, *43*, pp.699-708.

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.

Srinivasarao, C., Gopinath, K. A., Venkatesh, G., Dubey, A. K., Wakudkar, H., Purakayastha, T. J., Pathak, H., Jha, P., Lakaria, B. L., Rajkhowa, D. J. and Mandal, S., 2013. Use of biochar for soil health enhancement and greenhouse gas mitigation in India: Potential and constraints.

Toková, L., Igaz, D., Horák, J. and Aydin, E., 2020. Effect of biochar application and re-application on soil bulk density, porosity, saturated hydraulic conductivity, water content and soil water availability in a silty loam HaplicLuvisol. *Agronomy*, *10*(7), p.1005.

Topoliantz, S., J. F. Ponge, D. Arrouays, S. Ballof, P. Lavelle, 2002. Effect of organic manure and endogeic earthworm *Pontoscolex corethrurus* (Oligochaeta: Glossoscolecidae) on soil fertility and bean production, Biol. Fertil. Soils, 36: 313-319.

Uchimiya, M., Klasson, K. T., Wartelle, L. H. and Lima, I. M., 2011. Influence of soil properties on heavy metal sequestration by biochar amendment: 1. Copper sorption isotherms and the release of cations. *Chemosphere*, *82*(10), pp.1431-1437.

Uzoma, K. C., Inoue, M., Andry, H., Fujimaki, H., Zahoor, A. and Nishihara, E., 2011.Effect of cow manure biochar on maize productivity under sandy soil condition. *Soil use and management*, *27*(2), pp.205-212.

Vaccari, F. P., Baronti, S., Lugato, E., Genesio, L., Castaldi, S., Fornasier, F. and Miglietta, F., 2011. Biochar as a strategy to sequester carbon and increase yield in durum wheat. *European journal of agronomy*, *34*(4), pp.231-238.

Van Zwieten, L., Chan, K. Y., Meszaros, I., Downie, A. and Joseph, S., 2008. Using poultry litter biochars as soil amendments. *Soil Research*, *46*(5), pp.437-444.

Van Zwieten, L., Kimber, S., Downie, A., Morris, S., Petty, S., Rust, J. and Chan, K. Y., 2010. A glasshouse study on the interaction of low mineral ash biochar with nitrogen in a sandy soil. *Soil Research*, *48*(7), pp.569-576.

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

Warnock, D. D., Lehmann, J., Kuyper, T. W. and Rillig, M. C., 2007. Mycorrhizal responses to biochar in soil–concepts and mechanisms. *Plant and soil*, *300*, pp.9-20.

Yoo, J. C., Beiyuan, J., Wang, L., Tsang, D. C., Baek, K., Bolan, N. S., Ok, Y. S. and Li, X. D., 2018. A combination of ferric nitrate/EDDS-enhanced washing and sludge-derived biochar stabilization of metal-contaminated soils. *Science of the total environment*, *616*, pp.572-582.

Yuan, J. H., Xu, R. K., Qian, W. and Wang, R. H., 2011. Comparison of the ameliorating effects on an acidic ultisol between four crop straws and their biochars. *Journal of soils and sediments*, *11*, pp.741-750.

Zhang, Q.; Song, Y.; Wu, Z.; Yan, X.; Gunina, A.; Kuzyakov, Y.; Xiong, Z. Effects of six-year biochar amendment on soil aggregation, crop growth, and nitrogen and phosphorus use efficiencies in a rice-wheat rotation. J. Clean. Prod. 2020, 242, 118435.

Zhang, X., Gao, B., Zheng, Y., Hu, X., Creamer, A. E., Annable, M. D. and Li, Y., 2017. Biochar for volatile organic compound (VOC) removal: Sorption performance and governing mechanisms. *Bioresource technology*, *245*, pp.606-614.

Zimmerman, A. R., Gao, B. and Ahn, M. Y., 2011. Positive and negative carbon mineralization priming effects among a variety of biochar-amended soils. *Soil biology and biochemistry*, *43*(6), pp.1169-1179.

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