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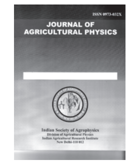

Review Article

Effect of Agricultural Residue Biochar on Soil Properties and Crop Yield – Review

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ABSTRACT

Presently the demand for agro-residues as alternatives to woody cellulosic fibres has risen due to the increased awareness of global deforestation and environmental concerns of burning the residues, and also the low cost of the residues compared to other plant fibres. The biochar (pyrolysis product of agricultural waste) has been used as a soil conditioner; however, the quantity, nutrients dynamics and contaminants of biochar is influenced by raw material used and pyrolysis temperature. The biochar incorporation in soil can alter soil texture, structure, pore size distribution and density, soil aeration and water holding capacity. Its application lead to decrease nutrient leaching and contaminant transport below the root zone and increase nutrient use efficiency by increasing water and nutrient retention and availability. Biochar can both increase and decrease the accessibility of soil organic matter to microorganisms and enzymes. Its soil application leads to boost water retention, therefore, have a positive effect on soil organism activity, which may well lead to parallel increases in soil functioning and ecosystem. The biochar, due to its high porous nature increased levels of refugia where smaller organisms can live in small spaces which larger organisms cannot enter to prey on them. Microorganisms within these micro pores are likely to be restricted in growth rate due to relying on diffusion to bring necessary nutrients and gases, but as this occurs in micro pores within the soil, this demonstrates that microorganisms utilising these refugia almost certainly would not be reliant of decomposition of the biochar for an energy source. The benefits at field application, it is reported that biochar increases crop productivity, varied with amount and crop type. The nature and mechanistic basis for interactions between crop, soil type, biochar feedstock, and production method and application rate will have to be understood to gain predictive capacity for the performance of biochar in soil, and open the possibility for large scale exploitation.

Key words: Agricultural residue, Biochar, Crop yield, Pyrolysis, Soil properties

Introduction

In India sustainable agricultural growth and food safety will be one of the main challenges. About 70% Indian population is living in rural areas with agriculture as their main livelihood supporting system. In country majority of farmers are small and marginal lands holding, due to continuous population growth and fragmentation of the land holdings. The quality of the land is deteriorating due to adverse effect of climate change and accumulation of toxic elements in soil and water, excess nutrient mining, soil erosion and increasing water scarcity. Land degradation is an emerging issue in several countries including India as a consequence of climatic variability. Land degradation is impoverishment of the land by human activities and by natural causes. The loss of arable land has been caused by a number of factors, many or most of which are tied to

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human development. It has been grouped into five classes: water erosion, wind erosion, soil fertility decline, soil salinization and water logging. The NBSS&LUP estimates projected an area of 187 M ha as degraded lands in 1994 following GLASOD methodology (Oldeman, 1988), and revised it to 147 M ha in 2004. As per estimates of ICAR (2010), out of total geographical area of 328.73 M ha, about 120.40 M ha is affected by various kind of land degradation. This includes water and wind erosion (94.87 M ha), water logging (0.91 M ha), soil alkalinity/sodicity (3.71 M ha), soil acidity (17.93 M ha), soil salinity (2.73 M ha) and mining and industrial waste (0.26 M ha). Furthermore, according to Anonymous (2019) India faces a severe problem of land degradation and about 29% (96.4 M ha) lands are considered as degraded. Total degraded and wastelands in Punjab state account for 494 thousand ha with highly degraded district Hoshiarpur > Rupnagar > Gurdaspur > Nawanshahre and Sangrure accounted 119, 66, 60, 48 and 47 thousand ha land, respectively (Trivedi, 2010). Further, Batish (2018) reported that 228.84 thousand ha (4.54%) land is suffering from different kind of soil problems out of total land area of 503.60 thousand ha. Biochar is a charcoal to be incorporated into the soils to improve soil fertility and, in addition, to mitigate climate change through carbon sequestration (Biederman and Harpole, 2013). Biochar has received interest for improving the degraded poor soils. However, although considerable research on biochar in recent years has yielded promising results, these are inconsistent and the mechanisms leading to better soil fertility and higher yields are not yet well understood (Jeffery *et al.,* 2011; Kookana *et al.,* 2011). The main hypothesis of the current study is to highlight the effect of agricultural residue biochar on soil properties and crop yield.

Agricultural Residue Biochar

The agricultural residues are materials left in an agricultural field or orchard after the crop has been harvested. There are readily available and low-cost renewable lignocellulosic fibre resources that can be used as an alternative to woody lignocellulosic biomass. The major ligno-cellulosic agricultural residues are wheat, rice, barley straw, corn stover, sorghum stalks, coconut husks, sugarcane bagasse, pineapple and banana leaves. These residues have similar structure, composition and properties to those of other plant fibres and make them suitable for composite, textile and pulp and paper application. The demand for agro-residues as alternatives to woody cellulosic fibres has risen recently due to the increased awareness of global deforestation and environmental concerns of burning the residues, and also because of the low cost of the residues compared to other plant fibres. Biochar is a simple and sustainable tool for the management of agricultural wastes. It helps in waste recycling as animal and crop wastes used in biochar manufacturing and converted into bio-energy, which is quiet useful. Agricultural residue biochar is produced by the pyrolysis of agricultural waste such as wood, sewage, green waste, poultry litter, peanut hulls, pine chips, waste water sludge, rice husks, paper pulp and other organic wastes in an oxygen-limited environment, usually at temperatures of 350°C–600°C (Hu *et al.*, 2013; Singh and Raven, 2017). The agricultural waste biomass can be broadly categorised as woody- and non-woody feedstock (Fig. 1). The biochar is manufactured by thermal decomposition of organic wastes under limited or complete absence of oxygen. There are many technological interventions available to produce it, consideration of two things keep critical importance in production of biochar i.e. type of organic wastes and conditions under which this organic waste is heated also known as pyrolysis conditions.

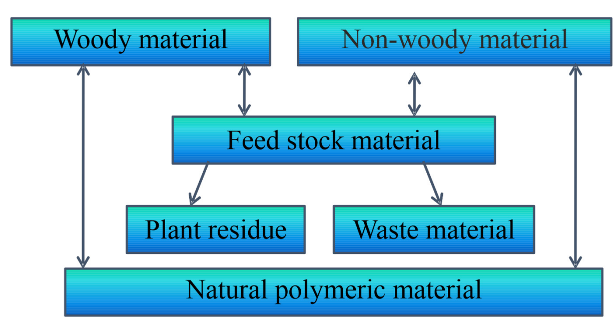

Fig.1. Categories of feedstock materials for biochar

Characteristics of Agricultural Residue Biochar

India generates about 350 million tonnes of agricultural waste every year and agricultural industry produces billions of tons of residues in non-edible portions derived from the cultivation and processing of a particular crop (Santana-Méridas *et al.*, 2012). Number of the agricultural and forestry residues can be used to produce bio-char and applied to agricultural soils for sequester C and to improve crops production potential. All agricultural waste materials are not suitable for bio-char production, including many field or vegetable crop residues with the notable exception of rice husks (FFTC, 2001), which has high amount of silica entrapping C during combustion (Hossain *et al.*, 2018). Rice husks are typically regarded as a waste product, but can be used to sequester C by producing bio-char. The residues from sawmills, forest residues, or nut shells, have high lignin concentration, are most suitable materials for yielding as bio-char (Demirbas, 2004). The feedstocks, along with pyrolysis conditions are the most important factor that controlling the properties of the resulting biochar. The chemical and structural composition of feedstock relates to the chemical and structural composition of the resulting biochar and thus reflected its behaviour, function and fate in soils. Further, the extent of the physical and chemical alterations undergone by the biomass during pyrolysis (e.g. attrition, cracking, microstructural rearrangements) is dependent on the processing conditions (mainly temperature and residence times). Cellulose and lignin undergo thermal degradation at temperatures ranging between 240-350°C and 280-500°C, respectively (Demirbas, 2004). The relative proportion of each component will, therefore, determine the extent to which the biomass structure is retained during pyrolysis, at any given temperature. For example, pyrolysis of wood-based feed stocks generates coarser and more resistant biochar with carbon contents up to 80%, as the rigid ligninolytic nature of the source material is retained in the biochar residue (Winsley, 2007). Biomass with high lignin contents (e.g. olive husks) have shown to produce some of the highest biochar yields, given the stability of lignin to thermal degradation (Demirbas, 2004). Therefore, for comparable temperatures and residence times, lignin loss is typically less than half of cellulose loss (Demirbas, 2004). Whereas woody feedstock generally contains low proportions (< 1% by weight) of ash, biomass with high mineral contents such as grass, grain husks and straw residues generally produce ash-rich biochar (Demirbas, 2004). These latter feed stocks may contain ash up to 24% or even 41% by weight, such as rice husk (Amonette and Joseph, 2009) and rice hulls (Antal and Grønly, 2003), respectively. The mineral content of the feed stock is largely retained in the resulting biochar, where it concentrates due to the gradual loss of C, hydrogen (H) and oxygen (O) during processing (Demirbas, 2004). The mineral ash content of the feedstock can vary widely and evidence seems to suggest a relationship between that and biochar yield (Amonette and Joseph, 2009). Many different materials including wood, grain husks, nut shells, manure and crop residues have been proposed as feed stocks for biochar, while those with the highest carbon contents (e.g. wood, nut shells), abundance and lower associated costs are currently used for the production of activated carbon (Lua *et al.,* 2004; Gonzaléz *et al.,* 2009). Other feed stocks are potentially available for biochar production, among which bio waste (e.g. sewage sludge, municipal waste, chicken litter) and compost. Rice husk (220 g kg^{-1}) and rice straw (170 g kg^{-1}) contain high levels of silica compared to other crops. High concentrations of calcium carbonate ($CaCO_3$) can be found in pulp and paper sludge (Van Zwieten *et al.*, 2007) and are retained in the ash fraction of some biochar. Regarding the characteristics of some plant feed stocks, Collison *et al.* (2009) suggested that even within a biomass feed stock type, different composition may arise from distinct growing environmental conditions (soil type, temperature and moisture content) and those relating to the time of harvest. Lingo cellulosic biomass is an obvious feedstock choice because it is one of the most abundant naturally occurring available materials (Amonette and Joseph, 2009). Nowadays any biomass material, including waste, is considered as a feedstock for biochar production. Still careful consideration needs to be given for specific tree species that bio accumulate specific metals. Similar in the case of crop residues, that may contains relevant concentrations of herbicides, pesticides, fungicides, and in the case of animal manures that may contain antibiotics or their secondary metabolites. The physico-chemical characteristic of biochar is influenced by the properties of the feedstock and pyrolysis conditions, such as temperature and furnace residence time (Gaskin *et al*., 2008). During pyrolysis, biomass undergoes a variety of physical, chemical and molecular changes. A significant loss in mass causes during pyrolysis due to volatilization and much change to the original structure of the feedstock caused as volume reduction and shrinkage (Laine *et al*., 1991). In addition, pyrolysis affects cation exchange capacity (CEC), pH and carbon content of biochar (Wu *et al*., 2012). Such as, decrease the CEC and increase the pH of biochar is observed by Wu *et al*. (2012) due to high pyrolysis temperature (700°C) as compared to low temperature (300°C). Moreover, pyrolysis alters the nutrient content of biochar, which affects nutrient uptake by plants. Increased in nutrient content with thermal degradation can be explained by loss of volatile compounds (C, H, and O) of the original material (Chan and Xu, 2009) and relatively little losses of alkali nutrients in the gaseous period. Similarly, some of the alkali nutrients can be lost through volatilization (Salazar *et al*., 2012). However, P and K vaporized at temperatures above 760°C, and Ca and Mg are lost only above 1240°C and 1107°C, respectively (Knicker, 2007). The biochar had high C content, likely to due to slow pyrolysis temperature and feedstock. A slow pyrolysis at low temperature for a long period results in higher biochar yields compared to high temperature pyrolysis (Bruun *et al.,* 2011). Brewer *et al.* (2011) showed that a biochar property depends on feedstock such as, wood biochar contain 62–79% carbon and 4–23 wt. % ash, switch grass and corn stove biochar contain 22–43% carbon and high ash 44–73 wt. %, pyrolysis at same temperature. The biochar may be contaminated by organic, metal, and ash contaminants (by-products) during the pyrolysis process (Lucchini *et al*., 2014). The molecular compositions of carbon in biochar affect its decay and stability in the soil (Lehmann, 2007). The low ratios indicate that the biochar carbon is very stable and likely to be recalcitrant (long-lasting) and has good carbon sequestration potential (Krull *et al.,* 2009; Mankasingh *et al.,* 2011). Slow breakdown leads to a decrease in CO_2 fluxes. The biochar produced under low temperature pyrolysis, is most polar with high O/C and O+N/C ratios, which may affect water holding capacity, movement of nutrients and heavy metals (Pb, Cd, Zn) in the soil (Cao *et al*., 2009; Ahmad *et al*., 2012).

Effects of Agricultural Residue Biochar on Soil Properties

The effect of agricultural residue biochar on soil is mainly reflected on physical structure, chemical properties and soil microbial content, etc. The typical effects of applied biochar to the soil are summarized in Table 1.

Effect on soil physical properties

The biochar incorporation in the soil can alter soil physical properties such as texture, structure, pore size distribution and density with implications for soil aeration, water holding capacity, plant growth and soil productivity (Downie *et al.,* 2009). The effect on soil physical properties depends on interaction of biochar with the physico-chemical characteristics of soil, and other determinant factors such as climatic conditions of the site, and the management of biochar application. The biochar application reduced the bulk density of soil, as biochar has a much lower bulk density than that of mineral soils, however, if the biochar that is applied has a low mechanical strength and disintegrates relatively quickly into small particles that fill up existing pore spaces in the soil, then the dry bulk density of the soil increased. The very low elasticity of biochar increased the soil resilience to compaction. The resistance to compaction of soil with biochar could potentially be enhanced direct or indirect effects (i.e. interaction with

Table 1. Effects of agricultural residue biochar on soil properties

Soil properties	Effects
Soil physical properties	• Decreased Soil bulk density (Chan and Xu, 2009; Mukherjee and Lal, 2013; Aslam *et al.,* 2014; Hseu *et al.,* 2014; Giab *et al.,* 2016; Pandian *et al.,* 2016; Adekiya *et al.,* 2020). • Enhanced soil water-holding capacity and soil water permeability (Asai *et al*., 2009; Downie *et al.,* 2009; Laird *et al*., 2010; Karhu *et al*., 2011; Hseu *et al.,* 2014; Koide *et al.,* 2015; Pandian *et al.,* 2016; Adekiya *et al.,* 2020). • Saturated hydraulic conductivity (Asai *et al*., 2009; Uzoma *et al.,* 2011; Lei and Zhang, 2013). • Reduced soil strength (Chan *et al*., 2008; Busscher *et al*., 2010; Lehmann *et al.,* 2011; Biederman and Harpole, 2013; Hseu *et al.*, 2014; Atucha and Litus, 2015). • Improved aggregate stability (Busscher *et al*., 2010; Peng *et al*., 2011; George *et al.,* 2012; Liu *et al.,* 2012; Curaqueo *et al.,* 2014; Hseu *et al.,* 2014; Gul *et al.,* 2015; Gamage *et al.,* 2016; Obia *et al.,* 2016).
Soil chemicalproperties	• Increased soil pH (Peng *et al*., 2011; Uzoma *et al.,* 2011; Quilliam *et al.,* 2012b; Biederman and Harpole, 2013; Curaqueo *et al.,* 2014; Gul *et al.,* 2015; Conversa *et al.,* 2015; Güereña *et al.,* 2015; Pandian *et al.,* 2016). • Increased cation exchange capacity (CEC) (Chan *et al*., 2007; Laird *et al*., 2010; Van Zwieten *et al*., 2010; Peng *et al*., 2011; Sukartono *et al.* 2011; Pandian *et al.,* 2016). • Reduced N leaching (Chan *et al*., 2007; Van Zwieten *et al*., 2010). • Increased soil nutrient (N,P, K) content (Yamato *et al.,* 2006; Atkinson *et al.,* 2010; Biederman and Harpole, 2013; Liu *et al.,* 2014; Zhu *et al.,* 2014; Bai *et al.,* 2015; Pandian *et al.,* 2016).
Soil biologicalproperties	• Increased soil microbial population (Khodadad *et al.,* 2011; Lehmann *et al.,* 2011; Ameloot *et al.,* 2013; Jaafar *et al.,* 2014; Pandian *et al.,* 2016). • Enhanced biological N fixation (Rondon *et al*., 2007; Mia *et al.,* 2014; Guereña *et al.,* 2015) • Improved colonisation of mycorrhizal fungi (Ezawa *et al.,* 2002; Blanke *et al.,* 2005; Warnock *et al.,* 2007).

SOM dynamics and soil hydrology). The biochar application in soil may also increased the soil surface area (Chan *et al.,* 2007) and consequently, improved soil water retention (Downie *et al.,* 2009) and soil aeration, mainly in fine-textured soils (Kolb *et al.*, 2007). An increased in soil-specific surface area may also benefited to native microbial community and the overall sorption capacity of soils. In addition, soil hydrology may also affect by partial/total blockage of soil pores by the smallest particle size fraction of biochar, thereby decreasing water infiltration rates. Biochar incorporation in soil can have direct or indirect effect on soil water retention, which can be short or long lived. Water retention of soil is determined by the distribution and connectivity of pores in the soil-medium, which is largely regulated by soil particle size (texture), combined with structural characteristics (aggregation) and SOM content. The direct effect of biochar on soils is related to the large inner surface area of biochar. Kishimoto and Sugiura (1985) reported the inner surface area of charcoal range from 200 to 400 m^2 g^{-1} formed between 400 and 1000°C. Latter, Van Zwieten *et al.* (2010) measured the surface area of biochar derived from paper mill waste was 115 m^2g^{-1}, prepared under slow pyrolysis. The biochar can also affect soil aggregation due to interactions with SOM, minerals and microorganisms. The matured biochar generally has a high CEC, increasing its potential to act as a binding agent of organic matter and minerals. Macro-aggregate stability was reported to increase with 20 to 130% with application rates of coal derived humic acids between 1.5 Mg ha^{-1} and 200 Mg ha^{-1} (Mbagwu and Piccolo, 1997). The high amount of biochar in soils darken its colour. Briggs *et al.* (2005) measured changes in dry soil colour from charcoal additions and found the Munsell value to decrease from 5.5 to 4.8 at charcoal of 10 g kg^{-1}, and down to 3.6 at 50 g kg^{-1}. Latter on Oguntunde *et al.* (2008) compared the soil colour of charcoal sites (i.e. where charcoal used to be produced) with that of adjacent soil and found the Munsell value to decrease from 3.1 to 2.5.

Effect on soil chemical properties

The cation exchange capacity (CEC) of soils is a measure for how well some nutrients (cations) are bound to the soil, and, therefore, available for plants uptake and 'prevented' from leaching to ground and surface waters. The CEC of biochar was correlated to the mean temperature and the extent of biochar oxidation (Cheng *et al.,* 2008) and was related to its external surface area, which was 7 times higher on the external surfaces than it's internal. The application of biochar lead to decreased nutrient leaching and contaminant transport below the root zone and increased nutrient use efficiency by increased water and nutrient retention and availability, related to an increased internal reactive surface area of the soil-biochar matrix, decreased water percolation below the root zone related to increased plant water use and increased plant nutrient use through enhanced crop growth. Higher retention times also permit a better decay of organic material and promote the breakdown of agrichemicals. Biochar directly contributes to nutrient adsorption through charge or covalent interactions on a high surface area. The leaching losses of nutrients can be minimized by nutrient adsorbing capacity of biochar in sandy soils with low clay contents (Major *et al.,* 2009). Steiner (2004) attributed decreased leaching rates of applied mineral fertiliser N in soils amended with charcoal to increased nutrient use efficiency. Similarly, Rondon *et al.* (2007) reported the biological N fixation by common beans was increased with biochar additions of 50 g kg^{-1} soil. Besides physical and chemical stabilization mechanisms, the phenomenon of co-metabolism may also affect the residence time of biochar in soils. This is where biochar decay is increased due to microbial metabolism of other substrates, which is often increased when SOM is 'unlocked' from the soil structure due to disturbance (e.g. addition of biochar into the soil via tillage). One potential mechanism is the oxidation of the functional groups at the surface of the charcoal, which favours interactions with soil organic and mineral fractions (Glaser *et al.,* 2002).The interactions between SOM and soil minerals have received considerable attention in the literature. Von Lützow *et al.* (2006) concluded that some evidence exists for interactions between biochar and soil minerals, leading to accumulation in soil, but that the mechanisms responsible are still unknown.

Effect on soil biological properties

Biochar can both increase and decrease the accessibility of SOM to microorganisms and enzymes. Brodowski *et al.* (2006) provided evidence that a significant portion of biomass carbon occurs in the aggregate-occluded OM in soil. Interestingly, the largest biomass carbon occurred in micro aggregates (<250 µm) and it has been suggested that it may be actively involved in the formation and stabilisation of micro aggregates, comparatively to other forms of organic matter (Brodowski *et al.,* 2006). The soil biota is vital to the functioning of soils and provides many essential ecosystem services. It is largely through interactions with the soil biota, such as promoting arbuscular mycorrhizal fungi (AMF) as well as influences on water holding capacity, which leads to the reported effects of biochar on yields. Soil is a highly complex and dynamic habitat for organisms, containing many different niches due to its incredibly high levels of heterogeneity at all scales. On the micro scale, soil is often an aquatic habitat, as micro pores in soil are filled with water at all times, apart from very extreme drought, due to the high water tension which exists there. This is vital for the survival of many microbial species which require the presence of water for mobility as well as to function. Indeed, many soil organisms, specifically nematodes and microorganisms such as protozoa enter a state of cryptobiosis, whereby they enter a protective cyst form and all metabolism stops in the absence of water. When biochar application leads to an increased water retention of soils, it seems likely, therefore, that this will have a positive effect on soil organism activity, which may well lead to concurrent increases in soil functioning and the ecosystem services which it provides. Organisms in the soil form complex communities and food webs and engage in many different techniques for survival and to avoid becoming prey, ranging from hiding in safe refuges, through to conducting forms of chemical 'warfare'. Biochar, due to its highly porous nature, has been shown to provide increased levels of refugia where smaller organisms can live in small spaces which larger organisms cannot enter to prey on them. Microorganisms within these micro pores are likely to be restricted in growth rate due to relying on diffusion to bring necessary nutrients and gases, but as this occurs in micro pores within the soil, this demonstrates that microorganisms utilising these refugia almost certainly would not be reliant of decomposition of the biochar for an energy source. This is likely to be one of the mechanisms for the demonstrated increases in microbial biomass (Steiner *et al.,* 2008; Kolb *et al.,* 2009) and combined with the increased water holding potentials of soil is a possible mechanisms for the increased observed basal microbial activity (Steiner *et al.,* 2008; Kolb *et al.,* 2009). Kolb *et al.* (2009) also stated that while charcoal additions affected microbial biomass and microbial activity, as well as nutrient availability, differences in the magnitude of the microbial response was dependent on the differences in base nutrient availability in the soils. However, they observed that the influences of biochar on the soil micro biota acted in a relatively similar way in the soils they studied, albeit at different levels of magnitude, and so suggested that there is considerable predictability in the response of the soil biota to biochar application. As with all interactions between the soil biota and biochar, there is a scarcity of data regarding the interaction of biochar with fungi. However, considering the diverse saprophytic abilities of fungi it is probable that the interaction between fungi and biochar is most likely to affect the stability and longevity of biochar within the soil. There is evidence of longer stability times of biochar in soils from Terra Pretas, biochar from different sources and exposed to different fungal communities may well have differing levels of recalcitrance and hence longer stability times in soils. Therefore, it is a highly pertinent area for further research. There is some evidence that the positive effects of biochar on plant production may be attributable to increased mycorrhizal associations (Warnock *et al*., 2007). The majority of studies concerning biochar effects on mycorrhiza show that there is a strong positive effect on mycorrhizal abundance associated with biochar in soil (LeCroy *et al.,* 2013; Blackwell *et al*., 2015; Vanek and Lehmann, 2015). Biochar, immediately after pyrolysis, can have a wide range of compounds on its surface. These can be included that are easily metabolised by microbes, such as sugars and aldehydes which are turned over quickly, but may also include compounds which have bactericidal and fungicidal properties such as formaldehyde and cresols (Painter, 2001). However, stability times of these substrates has been shown to be in the range of one to two seasons and, therefore, long term effects of these chemicals on the soil biota are improbable. Quilliam *et al.* (2013) concluded that after three years in field soil, the hardwood biochar was not a particularly attractive environment for microbial colonization. While, Tsai *et al*. (2009) reported considerably higher colonization rates on biochar particles from Amazonian Dark Earths. When added to soil, biochar has been shown to cause a significant increase in microbial efficiency as a measure of units of CO_2 released per microbial biomass carbon in the soil as well as a significant increase in basal respiration (Steiner *et al*., 2008). Steiner *et al.* (2008) also found that the addition of organic fertiliser amendments along with biochar lead to further increases in microbial biomass, efficiency in terms of CO_2 release per unit microbial carbon, as well as population growth and concluded that biochar can function as valuable component of the soil system, especially in fertilised agricultural systems. As well as increasing basal respiration and microbial efficiency, there is experimental evidence that biochar addition to soil increases N_2 fixation by both free living and symbiotic diazotrophs (Rondon *et al*., 2007). However, there is lack of information available with regard to the interaction of biochar with the soil meso and macrofauna, with the exception of earthworms. Both the application rate of biochar and the original feedstock used have been shown to affect the soil biota. Weyers *et al.* (2009) reported that application rates higher than 67 Mg ha^{-1} of biochar made from poultry litter had a negative impact on earthworm survival rates may be due to increased soil pH or salt levels. They noted that earthworm activity was greater in soil amended with pine chip biochar than with poultry litter biochar and so concluded that different types of biochar can have different effects on the soil biota (Chan *et al*., 2008).

Effect on degraded soil

Soil salinization is defined as the accumulation of water soluble salts in the soil, causing a deterioration or loss of one or more soil functions. The accumulated salts include Na, K, Mg and Ca, Cl, SO_4, CO_3 and HCO_3 (Jones *et al.,* 2008). A difference can be made between primary and secondary salinization processes. Primary salinization involves accumulation of salts through natural processes such as physical or chemical weathering and transport from saline geological deposits or groundwater (Huber *et al.,* 2008). Secondary salinization is caused by human interventions such as inappropriate irrigation practices, use of salt-rich irrigation water and (or) poor drainage conditions (Huber *et al.,* 2008). Salts associated with biochar should be considered as a potential source for secondary salinization. Various salts can be found in the ash fraction of biochar, depending mostly on the mineral content of the feedstock and the ash content of biochar varies from 0.5-55%. The good quality charcoal is referred to as having 0.5-5.0% ash (Antal and Gronli, 2003). However, biochar produced from feed stocks such as switch grass and maize residue have been reported to have an ash content 26-54% much of which as silica, while hardwood ash contains mainly alkali metals (Brewer *et al.,* 2009). A wide range of trace elements have been measured in biochar ash, e.g. B, Cu, Zn etc., however, the most common elements are K, Ca, Si and in smaller amounts Al, Fe, Mg, P, Na and Mn. These elements are all in oxidised form, e.g. Na_2O, CaO, K_2O, but can be reactive or soluble in water to varying degrees. It is the ash fraction that provides the liming effects of biochar that is discussed as a potential mechanism of some reported increases in plant productivity. However, for soils that are salinized or are sensitive to become salinized, that same ash fraction might pose an increased threat.

Effect of Agricultural Residue Biochar on Crop Yield

The majority of currently published studies assessing the effect of biochar on crop yield are generally small scale, almost all short term, and sometimes conducted in pots where environmental fluctuation is removed. These limitations are compounded by a lack of methodological consistency in nutrient management and pH control, biochar type and origin. Studies in a wide range of climates, soils and crops have been conducted. Therefore, it is not possible at this stage to draw any quantitative conclusion, certainly not to project or compare the impact of a particular one-time addition of biochar on long-term crop yield. Nonetheless, evidence suggests that at least for some crop and soil combinations, moderate additions of biochar are usually beneficial, and in very few cases negative. Glaser *et al.* (2002) observed that 67 Mg ha^{-1} and 135 Mg ha^{-1} biochar increased cowpea biomass by 150% and 160% on xanthic ferralsol. Oguntunde *et al.* (2004) comparied the maize yields between charcoal production sites and adjacent fields and observed 91% higher grain and 44% higher biomass yield on charcoal site than control. Higher rates seemed to inhibit plant growth. In later experiments, combination of higher biochar application rates alongside NPK fertiliser increased crop yield on tropical Amazonian soils (Steiner *et al.,* 2007). Rondon *et al.* (2007) reported that the positive effects of biochar, including increased N_2 fixation, lead to a between 30 and 40% increase in bean (*Phaseolus vulgaris* L.) yield at biochar additions of upto 50 g kg^{-1}. However, they found that at an application rate of 90 g kg^{-1} a negative effect with regard to yield occurred. The magnitude of radish yield response increased as the biochar application increased with nitrogen (Chang *et al.*, 2007). Further, Chang *et al.* (2008) reported significantly increased in total dry matter of radish with biochar without fertilizer application. Van Zwieten *et al.* (2010) conducted the trials with radish, wheat and soyabean. They concluded that calcarolsol soils, amended with fertilizer and biochar gave varied crop responses, where soybean biomass increased, but wheat and radish yield decreased. All trials conducted without fertilizer for wheat and soyabean had no significant result, while radish biomass showed increased response. Major *et al.* (2010) reported that the singal biochar application to the soil improved maize (*Zea mays*) yield upto 4 years after application. Baronti *et al*. (2010) reported that the 10t ha^{-1} biochar application increased 10% durum wheat yield in Italy. Application of cow manure biochar @ 15 and 20 t ha^{-1} significantly increased maize yield as compared with control in sandy soil, Uzoma *et al.* (2011). Liu *et al.* (2013) reported that increases in crop productivity varied with crop type with greater increases for legume crops (30%), vegetables (29%), and grasses (14%) compared to cereal crops corn (8%), wheat (11%), and rice (7%) with addition of biochar. The superior performance of maize under the biochar treatments was observed and 5 t ha^{-1} biochar applications showed higher maize grain yield over 2.5 t ha^{-1} (Yeboaha *et al.,* 2016). The nature and mechanistic basis for interactions between crop, soil type, biochar feedstock, and production method and application rate will have to be understood to gain predictive capacity for the performance of biochar in soil, and open the possibility for large scale deployment. Mohan *et al*. (2018) reported that the rice husk and corn stover) biochars improved soil fertility and significantly enhanced eggplant crop growth (height, leaf number, fresh and dry weight).

Conclusion

The present review concluded the potential of agricultural waste biochar behaviour on soil properties and crop production. All the agricultural waste materials are not suitable for biochar production due to high amount of silica entrapping C during combustion. The chemical and structural composition of feed stock, along with pyrolysis conditions are the most important factor that controlling the properties of the resulting biochar thus reflected its behaviour, function and fate in soils. Increased in crop yield was reported by many workers due to application of biochar, as biochar enhanced soil physico-chemical and biological properties. However, salts associated with biochar should be considered as a potential source for secondary salinization of soil. Moreover, further research is needed on the effects of different agricultural residue biochar amendments on soil quality and plant available water retention. The research on changes in soil characteristics caused by the biochar application and other soil amendments or fertilizers is insufficient. Therefore, research can be carried out separately from the aspects of physical structure, chemical properties and microorganisms in association with crop production.

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