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Comprehensive Study on Biochar and its Effect on Soil Properties: A Review

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A B S T R A C T

Soils in India are declining in fertility status due to higher usage of synthetic fertilizers and mono-cropping practices. To maintain the sustainability of soil and better crop production, it is essential to retain physical, chemical and biological properties of the soil through optimum level of organic matter. This article deals on the literature related to biochar, its production and characterization and its effect on soil application. The biochar application to the soil is a novel technique to improve soil fertility and thereby the soil productivity. The excess crop residues accumulated in the field after harvest can be utilized for biochar preparation along with inorganic fertilizers. Any waste material like wood chips, crop residues such as straw, husk, stover, trash and organic waste from industries can be effectively utilized for the production of biochar. Biochar from prosopis, cotton and maize which are available on-site have shown to significantly improve the soil physico-chemical parameters and thereby can be used as an alternative to other slow degrading bulky organic manures. The major cause for improvement in soil fertility on application of biochar is due to addition of organic carbon, slow release of applied nutrients through chelation effect, improved water holding capacity and porosity of soil.

Keywords

Biochar, Soil properties, Maize biochar, Cotton biochar, Prosophis biochar

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Introduction

The use of biochar, a porous, carbon rich material prepared from crop biomass through pyrolysis process could help in saving nutrient losses sustainably. The crop biomasses are subjected to thermo-chemical conversion under absence of oxygen with a temperature range 350°C to 500° C.

The properties of biochar material produced through pyrolysis process depend upon the biomass used and also the temperature involved in preparation. Biochar application into the soil as an amendment improves soil physical, chemical and biological properties and thereby solves many of the soil related issues (Singh *et al.*, 2012). Biochar is persistent in soils and its beneficial effects are longer lasting compared to other forms of organic matter. The unique nature of the biochar is that it retains most of the applied nutrients and makes them available to growing plants than other organic matter like on farm common leaf litter, compost or manures (Schulz *et al.,* 2013).

The excess crop residues accumulated in the field after harvest can be effectively utilized for biochar preparation. The different types of biochar in combination with organic and inorganic fertilizers significantly improve soil tilth (Glaser *et al.,* 2002), crop productivity (Graber *et al.,* 2010) and nutrient availability (Lehmann *et al.,* 2006; Silber *et al.,* 2010). The increase in crop yield in biochar incorporated soil was due to higher nutrient availability and concentrations of basic cations (Uzoma *et al.,* 2011).

In acid soils, liming effect of biochar enhances soil microbial diversity and its function, together with increasing cation exchange capacity and crop water availability (Anderson *et al.,* 2011). Sandy soils which have smaller surface area compared to other soil types, when applied with biochar improve the water holding capacity. Porous nature and higher surface area of biochar leads to retention of higher amount of soil moisture available for crop uptake (Fang *et al.,* 2014).

The biochar has major benefits like improving soil fertility, structure, water holding capacity, organic carbon content, increased biological activity, thereby, improved crop yield in a sustainable manner (Masto *et al.,* 2013). It also serves as better alternate for other organic manures as it does similar work as that of FYM and other composts. According to Zhang *et al.,* (2013) biochar is generated by thermo-chemical conversion of biomass under oxygen-limited conditions. Shackley *et al.,* (2012) defined "biochar is a carbon and energy-rich porous material produced through slow pyrolysis of biomass, which has been proposed as a way of storing carbon in soils for the long-term''. Xu *et al.,* (2013) reported that any organic residues can be converted into biochar through pyrolysis.

Raw materials for biochar production

Cantrell *et al.,* (2012) suggested that different types of materials like bark of the tree, wood chip and pellets, crop residues such as straw, rice husk, maize stover, cotton stalk and sugarcane trash and organic waste of paper sludge, sugarcane baggase, chicken litter, dairy manure and sewage sludge can be effectively utilized for the production of biochar.

Other agricultural residues like corn cob, corn stalk, wheat straw, rice straw, stalk of pearl millet, cotton, mustard, soybean and sugar beet crop residues and agro-industrial waste like paper mill waste, *Jatropha* husk, coffee husk, coconut shell and cocoa pod (Prabha *et al.,* 2015; Purakayastha *et al.,* 2015) also can be effectively utilized.

Venkateswarlu *et al.,* (2012) observed that crop residues of maize, castor, cotton and pigeonpea, glyiricidia twig, eucalyptus bark, pongamia shell, eucalyptus twig and leucaena twig from rainfed areas are burnt in the field as farmers are facing difficulties in disposing these residues and suggested that these can be effectively utilized for biochar production.

Biochar recovery

Venkateswarlu *et al.,* (2012) used pine needles, maize stalk and five weed biomasses for preparation of biochar and found that biochar recovery was higher in pine needles (47.72 per cent) and lowest recovery was recorded in setaria (23.23 per cent). Hernandez-Mena *et al.,* (2014) inferred that reduction in biochar output with the increase in reaction temperature during preparation of bamboo biochar. At 300°C, the biochar recovery was 60 per cent and at 600°C the biochar output was 30 per cent only.

Kamara *et al.,* (2015) opined that biochar recovery from the raw rice straw was on the average of 29.7 per cent with an ash content of 34.2 per cent. The biochar produced from rice straw recorded low bulk density (0.75), higher pH (9.3) and phosphorus (738 mg P kg^{-1} biochar).

Pandian *et al.,* (2016) concluded that the biochar conversion efficiency for prosopis was highest (45–52 per cent) followed by cotton stalk biochar (38–46 per cent), redgram stalk biochar (36–39 per cent), while maize stalk biochar recorded the lowest conversion efficiency of 32–35 per cent. The variations in recovery of biochar are mainly due to nature of the materials and pyrolysis temperature followed during the preparation.

Biochar yield of the crop residues varied from 20–25 per cent by weight. Shalini *et al.,* (2017) observed maximum biochar yield of 27.5 per cent by weight from *Coccus nucifera* compared to *Prosopis glandulosa* hard wood biochar (24.8 per cent). The recovery of biochar mainly depends on cellulose and lignin content in the biomass. Tan *et al.,* (2017) pointed out that at 600°C pyrolysis temperature, the biochar output of grass stalk was 16.1 per cent by weight whereas rape seed biomass recorded lower biochar yield of 8.5 per cent by weight.

Biochar properties

According to Lehmann (2007), biochar is primarily composed of condensed aromatic carbon ring and has higher surface area. Naeem *et al.,* (2014) and Dume *et al.,* (2015) indicated that quality and elemental compositions of the biochar mainly depend on production conditions specifically pyrolysis temperature and time duration for the process.

Physical properties of biochar

Porosity

Yu *et al.,* (2009) suggested that biochar influence soil water holding and adsorption capacity through its porous structure. Nutrient retention ability of the biochar mainly depends on porosity and surface area which binds cations and anions on its surface (Chan *et al.,* (2008). Lehmann and Joseph and Lehmann (2009) inferred that the porosity of biochar determined its surface area, labile pore size distribution *viz.* nano pores (< 0.9 nm), micro pores (< 2 nm) and macro pores (> 50 nm). Biochar produced at intermediate temperatures of 450˚C to 750˚C, had higher surface area of 200 to >500 m^2 g^{-1} and was highly porous in nature. Further, they concluded that the large surface area of the biochar increased the porosity and had positive effect on soil. Macro pores present in the soils promotes aeration and provided shelter space for microbes. Atkinson *et al.,* (2010) opined that micro pores were involved in molecule adsorption and transport.

Angın (2013) stated that the water holding ability and adsorptive capacity of biochar in soil was depends on macro porous structure of biochar. According to Rogovska *et al.,* (2014) biochar exhibit wide range of porosity and bulk density depending on source of biomass used and temperature maintained during pyrolysis process.

Bird *et al.,* (2011) indicated that porosity of the biochar increased with increase in pyrolysis temperature. Wang and Liu (2015) reported that leaching of nitrogen from the soil was inhibited in biochar added soil due to porosity and large surface area of applied material.

The adsorption ability of biochar mainly depends on pore structure and pore size.

Surface area

Day *et al.,* (2005) recorded increase in surface area of biochar from 120 m^2 g^{-1} at 400°C to 460 m^2 g^{-1} at 900°C due to increase in production temperature. This implied that biochar derived at lower temperature has the property to release fertilizer nutrients in slow manner. Chan *et al.,* (2008) observed that biochar derived from softwood had lower surface area and biochar from hardwood had higher surface area. The surface area of biochar prepared from various materials ranged from 200 to 300 m^2 g^{-1} and biochar produced at higher temperature had high surface area of more than 400 m^2 g^{-1}.

Schimmelpfennig and Glaser (2012) found that porous structure of biochar facilitate lower bulk density and results in higher specific surface area ranging from 50 – 900 m^2 g^{-1}. Clough *et al.,* (2013) opined that biochar serves as habitat for beneficial microorganisms for its multiplication due to its larger surface area and more porous structure. Tan *et al.,* (2017) concluded that the specific surface area of biochar is directly related with pyrolysis temperature and it was 0.16 m^2 g^{-1} at 300° C and 110 m^2 g^{-1} at 400 °C. The specific surface area increases rapidly with increase in temperature from 300 °C to 500 °C and slow rate of increase in surface area was observed above 500 °C.

Water holding capacity

Wang and Liu (2015) inferred that biochar produced different hard wood materials had good water holding capacity and maintained 72–86 per cent of saturation under free water flow conditions. Biochar from grass substrates showed slightly better water holding ability than the wood biochar. Karunakaran (2017) stated that rice husk biochar was more compact with higher ash content, more number of pores and thereby higher water holding capacity than coconut shell biochar.

Chemical properties of biochar

Organic carbon

Biochar derived from the wood materials recorded more carbon and low ash, nutrient and cation exchange capacity than biochar derived from manures (Singh *et al.,* 2010). Liang *et al.,* (2010) indicated that it can be directly applied to different crops as a slow release fertilizer to improve soil fertility and build soil carbon. An experiment conducted by Keiluweit *et al.,* (2010) revealed that the pyrolysis temperature of 550°C favours higher recovery of carbon and several nutrients like N, K, and S that are lost at higher temperatures. Incorporation of biochar into the soil results in the improvement soil organic carbon content as it contains higher organic carbon, resulting in mitigation of greenhouse gas emissions. According to Jha *et al.,* (2010) the total carbon content in different biochar materials ranged from 33.0 per cent to 82.4 per cent.

Wang and Gao (2015) reported that the organic carbon content was 564 g kg^{-1} at the temperature of 300°C and it decreased by 28.03 per cent when temperature was increased to 450°C and further it declined by 54.02 per cent at 600°C. This indicates that organic carbon decreases with increase in reaction temperature. Yulduzkhon (2014) observed that the apple-wood biochar had high carbon content (75 per cent) and low ash content (11.8 per cent) due to low pyrolysis temperature. Dume *et al.,* (2015) found that when biochar was produced in the temperature range from 350 to 500°C, organic carbon content was increased from 13.98 to

20.57 per cent in coffee husk biochar and 16.45 to 26.91 per cent in corn cob biochar.

Zheng *et al.,* (2018) inferred that application of biochar as nitrogenous fertilizer is less effective as it contains higher carbon content than nitrogen. The major element present in biochar is carbon (70-80 per cent by weight) with significantly lower nitrogen content (<3 per cent by weight). Mandal *et al.,* (2015) concluded that maximum total organic carbon content was recorded in biochar from *Avena fatua* (56.2 per cent) followed by Setaria (55.2 per cent), pine needles (54.6 per cent) and Gynura (53.9 per cent). Laghari *et al.,* (2016) opined that rice straw biochar had high carbon content of 871 g kg^{-1} as against 440 and 391 g kg^{-1} from manure and sludge-derived biochar, respectively.

Pandian *et al.,* (2016) evaluated organic carbon content in different biochar and recorded the value of 25–32 g kg^{-1} in prosopis biochar, 21–76 g kg^{-1} in maize stalk biochar, 24–76 g kg^{-1} in redgram stalk biochar and 17–69 g kg^{-1} in cotton stalk biochar. Total carbon content of different source of biochar varied from 66 per cent to 89 per cent and it was mainly due to accrual of carbon through process of pyrolysis and carbon content of the crop residue. The biochar recovery rate depends on temperature and feedstock materials used for preparation and higher carbon content was observed during low pyrolysis temperature of 400-450°C (Shalini *et al.,* 2017).

Hydrogen ion concentration (pH) and electrical conductivity (EC)

According to Chan *et al.,* (2008) variation in EC, pH, nitrogen and phosphorus concentrations occurred with the pyrolysis temperature when biochar were produced from same feedstock of chicken manure. Chan and Xu (2009) reported that wider variation in the pH and nutrient composition of N, P and K exist in the biochar produced from different organic materials. Yuan *et al.,* (2011) observed that increase in pyrolysis temperature leads to hydrolysis of carbonates and bicarbonates of base cations such as Ca, Mg, Na and K and also separation of cations and organic anions from source materials resulting in higher pH of biochar. Hernandez-Mena *et al.,* (2014) revealed that biochar produced from apple wood at higher temperature of 400°C shown higher pH value of 8.67. Wang and Gao (2015) found that pH of the biochar increased with pyrolysis temperature and this might be due to the fact that higher biochar production temperature could increase the percent of alkaline cations of Ca, Mg, K.

Laghari *et al.,* (2016) pointed out that the increase in pH range of 6.35 to 9.08 was observed at pyrolysis temperature from 400 to 800 °C. Pandian *et al.,* (2016) inferred that the highest pH value of 9.4 to 10.8 and electrical conductivity of 0.83–1.25 $dSm^{-1}$was recorded in prosopis biochar. Tan *et al.,* (2017) opined that the biochar produced from rice straw has maximum pH of 10.6, which is 11.2 per cent higher than that of bamboo biochar. Shalini *et al.,* (2017) reported that pH value of different biochar varied from 9.64 to 9.90 and maximum was recorded in *Prosopis glandulosa* hard wood biochar which can be used for acid soil reclamation.

Cation exchange capacity (CEC)

Quality of biochar is decided by source of organic materials used for production, adsorption capacity and cation exchange capacity. Over a period of time, decrease in biochar adsorption capacity and increase in cation exchange capacity was noticed (Chan *et al.,* 2008; McLaughlin, 2010). Lehmann *et al.,* (2009) and Wu *et al.,* (2012) revealed that biochar preparation temperature and feedstock material decides the CEC of biochar. Once biochar amended into the soil, CEC increases due to oxidization of the functional groups on the surface of biochar. According to Liang *et al.,* (2010) biochar contain many functional groups of hydroxyl and carboxyl and these plays major role in improvement of cation exchange capacity.

Jiang *et al.*, (2013) noted that cation exchange capacity of biochar mainly depends on its surface area, the existence of carboxyl functional groups, biomass materials and temperature during production process. Bera *et al.*, (2014) found that the biochar produced from wheat and rice showed higher cation exchange capacity than the biochar produced from other materials.

Narzari *et al.,* (2015) reported that the increase in CEC was significant with the increase in pyrolysis temperature and it was directly proportional to production temperature. Dume *et al.*, (2015) observed that biochar produced from coffee husk and corn cob at 500°C recorded higher CEC and phosphorus concentration.

Study conducted by Kamara *et al.,* (2015) revealed that the rice straw biochar recorded higher cation exchange capacity of 44.2 cmol kg^{-1} and was also rich in exchangeable cation K (39.7 cmol/kg) as compared to Mg and Ca (5.8 cmol kg^{-1} and 12.6 cmol kg^{-1}), respectively. The biochar produced from crop residues showed higher CEC (56.9 cmol kg^{-1}) followed by manure-derived biochar (47.0 cmol kg^{-1}). Laghari *et al.,* (2016) inferred that the cations of K, Na, Ca, Mg, and P present in the source materials promote the formation of oxygen containing functional groups on the surface of biochar during pyrolysis process that results in higher CEC of the biochar.

Tan and Lin (2017) concluded that the variation in CEC of biochar is probably due to different source of materials used for the preparation of biochar under different pyrolysis temperature and also functional groups present on the surface of the biochar. CEC of biochar are generally in the range of 5 and 10 cmol kg^{-1}.

Prosopis biochar

Shenbagavalli and Mahimairaja (2012) observed higher carbon content of 940 g kg^{-1} and C:N ratio of 83.9 in prosopis biochar. It also contains higher amount of cellulose (36 per cent) than the hemicelluloses (31 per cent) and the lignin content (22 per cent). Manikandan and Subramanian (2013) indicated that the prosopis biochar contained 86.5 per cent carbon, 1.56 per cent nitrogen, 55:1 C:N ratio, pH of 9.16 and EC of 0.15 dSm^{-1}. The bulk density, particle density and pore space percentage recorded in the prosopis biochar was 0.50, 0.71 g cc^{-1} and 30 per cent, respectively.

According to Gebremedhin *et al.,* (2015) properties of prosopis biochar viz. pH was almost neutral (6.8) with electrical conductivity of 86 dSm^{-1}, organic carbon content of 3.46 per cent, total nitrogen of 0.44 per cent and total phosphorus of 0.07 per cent. CEC of biochar widely varied with range from 11.50 to 16.70 cmol kg^{-1} and the maximum CEC was found in *Prosopis glandulosa* hard wood biochar (16.70 cmol kg^{-1}).

Shalini *et al.*, (2017) reported that the nutrient retention capacity of *Prosopis glandulosa* hard wood biochar is mainly dependent upon cation exchange capacity. Angalaeeswari and Kamaludeen (2017) observed that prosopis biochar has pH, EC and OC of 8.73, 2.2 dSm^{-1} and 8.90 per cent, respectively. The physical properties like bulk density, particle density, moisture and ash content were 0.34, 0.23, 0.35 and 1.29 per cent, respectively.

Cotton biochar

Decrease in yield of cotton stalk biochar from 37.35 per cent to 31.23 per cent and volatile matter content from 30.23 per cent to 13.76 per cent was noticed by Sun *et al.,* (2014) when temperature increased from 400°C to 800°C.

Venkatesh *et al.,* (2013) concluded that the Total C and N content of the cotton biochar ranged between 592 to 719 g kg^{-1} and 10.3 to 17.4 g kg^{-1}, respectively. Around 26 to 38 per cent of total carbon and 16 to 34 per cent of total nitrogen was recovered through production of biochar. Total nutrient contents of P, K, Ca, Mg, Fe, Cu, Mn and Zn in cotton biochar were higher as compared to cotton crop residue. The CEC of the cotton biochar ranged between 11.7 to 51.3 cmol kg^{-1}. The biochar produced at 450-500˚C possess maximum water holding capacity (3.9 g g^{-1} of dry biochar) and available water capacity (0.89 g g^{-1} of dry biochar). Coumaravel *et al.,* (2015) inferred that organic carbon content of cotton biochar was 174.6 g kg^{-1} and total N, P and K contents were 0.322, 0.0013 and 1.038 per cent, respectively. The EC of cotton biochar was recorded in the range between 0.58–0.85 dSm^{-1} by Pandian *et al.,* (2016). Zhang *et al.,* (2016) opined that the cotton stalk had ash content of 13 per cent on weight basis and biochar recovery of 42 per cent compared to other materials (28–35 per cent). It was also observed that the cotton biochar recorded 44.0 dSm^{-1} of EC, 24 per cent of organic carbon content, total carbon content of 55 per cent and high nitrogen content of 2.3 per cent.

Maize biochar

Venkateswarlu *et al.,* (2012) revealed that the pH of biochar from maize (10.7) and pearl millet (10.6) was higher as compared to biochar prepared from wheat (8.8) and rice (8.6). The maize biochar was low in bulk density, high in water holding capacity (45.6 per cent), low in carbon content (37 per cent) and rich in major (N, P and K), secondary (Ca and Mg) and micronutrient (Fe, Mn, Zn and Cu) content. Total carbon content was the highest in maize biochar (66 per cent) followed by biochar produced from pearl millet (64 per cent), wheat (64 per cent) and rice (60 per cent) (Bera *et al.*, 2014).

Mandal *et al.,* (2015) stated that phosphorus availability varied between the biochar and it was 3.32 mg kg^{-1} (*Lantana* biochar), 3.68 mg kg^{-1} (Maize stalk biochar) as compared to 3.14 mg kg^{-1} in control plot. According to Pandian *et al.,* (2016) the biochar obtained from maize stover recorded highest total N (0.45 per cent) and total P (0.84 per cent) than prosopis biochar.

Influence of biochar on soil properties

Physical properties

Soil porosity and surface area

Liang *et al.,* (2006) reported that biochar has greater surface area, negative surface charge and higher charge density resulting in better ability to adsorb cations than soil organic matter. Downie *et al.,* (2009) observed that biochar when added as amendment, increased total soil specific surface area due to higher specific surface of biochar leads to improvement in soil water retention. Zwieten *et al.,* (2010) found that distribution of pore size in biochar depends on structure of biomass and pyrolysis temperature. Woolf *et al.,* (2010) inferred that addition of biochar influenced soil structure, texture, porosity, particle size distribution and density. This leads to improvement of air content, water holding capacity, microbial and nutritional condition of the soil within the rhizosphere of plant.

Major *et al.,* (2010) concluded that addition of biochar to soils increased surface area, distribution of pore size and lower the soil bulk density resulted in improvement of soil structure and porosity. Verheijen *et al.,* (2010) revealed that increase or decrease of the overall porosity of soil mainly depend upon particle size, pore size distribution, connectivity, mechanical strength and interaction of biochar particles in the soil. Masulili *et al.,* (2010) stated that addition of rice husk biochar at the rate of 10 t ha^{-1} and 15 t ha^{-1} increased total porosity of the soil.

Macro pores present have the ability to promote aeration and provide space for microbes. Micro pores were involved with molecule adsorption and transport (Atkinson *et al.,* (2010). Herath *et al.,* (2013) indicated that the porosity of soil has been increased by addition of biochar and this increase depends on the biochar and soil type. According to Mukherjee and Zimmerman (2013) porous nature of biochar increased porosity of applied soil. Wang *et al.,* (2016) reported that addition of biochar on clay and poorly aggregated soils leads to less compacted soil and provide better aeration and increased moisture storage capacity.

Bulk density of soil

Liang *et al.,* (2006) revealed that application of biochar to soil improves aeration due its porous nature and soil aggregation. Reduction in bulk density of soil was observed when biochar added to soil due to lower bulk density (Gundale and DeLuca, 2006).

Atkinson *et al.,* (2010) found the reduction in bulk density of soil after addition of biochar and this in turn served as indicator for enhancement of soil structure and aeration. Mankasingh *et al.,* (2011) inferred that application of 6.6 t ha^{-1} of cassia biochar increased the carbon content, organic matter and reduction in soil bulk density. Bulk density of biochar was lower compared to mineral particles, its addition at higher rate decrease bulk density of soil. (Lehmann *et al.,* 2011; Alburquerque *et al.,* 2014).

Zhang *et al.,* (2012) concluded that consistent decrease in soil bulk density from 1.01 to 0.89 g cm^{-3} compared control when biochar was added in soil @ 40 t ha^{-1}. Githinji (2014) opined that significant decrease in bulk density was observed along with increasing rate of biochar application. Liu and Quek (2013) confirmed a decrease in soil bulk density and improvement in soil aggregate structure with biochar application, which ultimately increased total porosity in soil.

Glab *et al.,* (2016) observed improvement in physical properties of sandy soil after addition of biochar. The soil bulk density decreased and total porosity increased by the increasing rate of biochar. Low bulk density of 1.36 g cm^{-3} and higher pore space (47.5 per cent) were recorded in redgram stalk biochar @ 5 t ha^{-1} applied plots over control (Pandian *et al.,* 2016). Incorporation of biochar with low bulk density and stable organic carbon reduced the root penetration resistance and increased total soil porosity (Liu *et al.,* 2017).

Venkatesh *et al.,* (2018) reported positive effects of biochar incorporation on the soil health directly and indirectly. It changes soil physical properties like bulk density, soil structure, stability of soil, pore size distribution and density in correlation with aeration, water infiltration, and water holding capacity of the soil.

Soil chemical properties like nutrient retention, cation exchange capacity, pH and EC were changed positively. Apart from this it also reduced uptake of soil toxins and increased the population of beneficial soil microorganisms.

Water holding capacity

Addition of biochar improves water, air and nutrient levels in soil. The surface of biochar when oxidized, becomes hydrophobic in nature resulting in increased water absorbance and water holding capacity. Returning crop residues in the form of biochar into soils is more conducive to increase the water content of soils than direct application of crop residues (Downie *et al.*, 2009). The ability of biochar to hold higher quantity water facilitates its application on areas prone to drought. According to Chen *et al.*, (2010) application of biochar produced from bagasse increased available soil moisture which facilitated for higher yield and sugar content in sugarcane.

Karhu *et al.*, (2011) reported that biochar amended soil recorded an 11 per cent increase in water holding capacity and a profound effect on soil fertility through increased water retention. Sukartono *et al.*, (2011) observed that water use efficiency (WUE) of maize in coconut shell biochar applied plot was 9.44 kg mm^{-1} and for cattle dung biochar 9.24 kg mm^{-1}. Both the biochar improved water use efficiency in sandy loam soils and increased maize production. Abel *et al.*, (2013) stated that amendment of maize husk biochar influenced the soil properties and thereby increased total pore volume and water content up to 16.3 per cent.

Gururaj and Krishna (2016) pointed out that addition of biochar would be helpful to retain more amount water in soil. Biochar added soil recorded low water evaporation rate when compared to control. Pandian *et al.*, (2016) found that biochar incorporated @ 5 t ha^{-1} reduced the bulk density of soil from 1.41 to 1.36 g cm^{-3} and increased the soil moisture by 2.5 per cent. Biochar incorporation increased soil moisture in sandy loam soil due to the higher surface area and porous nature of biochar and simultaneously enhanced the infiltration of rainwater.

Chemical properties

Organic carbon

Wang and Liu (2015) inferred that biochar prepared from wheat straw and applied to calcareous soils of China @ 20 t ha^{-1} increased soil organic carbon and total nitrogen by 25–54 per cent and 4–12 per cent, respectively, whereas it had no effect on soil pH and available nitrogen. Mandal *et al.*, (2015) concluded that biochar produced from Gynura recorded highest increase in soil organic carbon (1.74 per cent), followed by biochar derived from weed species like Ageratum, Lantana and Setaria (1.70 per cent). Organic carbon content of the soil was increased with increasing application rate of biochar (150, 155, 165 and 175 g kg^{-1} after the application of 2 per cent, 3 per cent, 5 per cent and 10 per cent biochar respectively) and control registered lower carbon of 146 g kg^{-1} (Kaur and Sharma, 2015).

Rafi *et al.*, (2015) opined that application of biochar on an average increased total soil carbon in the range of 41 to 65 per cent. Maize stover and wheat straw biochar incorporated soils recorded highest total soil carbon compared to rice straw biochar treated soil. Study conducted by Coumaravel *et al.*, (2015) revealed that the organic carbon content of the soil varied between 3.22 g kg^{-1} to 5.91 g kg^{-1} and application of NPK (250:75:75 kg ha^{-1}) +FYM @12.5 t ha^{-1} + Biochar @ 15 t ha^{-1} + Azospirillum @ 2 kg ha^{-1} in maize recorded the highest organic carbon content (5.91 g kg^{-1}) than other treatments. Application of different sources of biochar had soil organic carbon (OC) content ranged between 4.4 and 4.8 g kg^{-1} and control had only 3.6 g kg^{-1} OC. The highest OC content (4.8 g kg^{-1}) was noticed in maize stalk biochar and redgram stalk biochar @ 5 t ha^{-1} applied plots (Pandian *et al.,* 2016). Rajagopal (2018) indicated that the carbon loss from biochar incubated soil was high during initial period of time and decreased latter and reaches constant value.

Hydrogen ion concentration (pH) and electrical conductivity

Zwieten *et al.,* (2010) reported that biochar can be used to improve soil pH as it decreases exchangeable aluminium and hydrogen ions by adsorption through basic cations like potassium, calcium and magnesium present in the biochar. According to Galinato *et al.,* (2011) biochar application had the ability to improve soil acidity by increasing pH for wheat cultivation from pH of 4.5 to 6.0 and thereby the yield was also increased from 3924 kg ha^{-1} to 6219 kg ha^{-1}. Soil pH was significantly increased when biochar was applied due to domination of carbonates of alkali and alkaline earth metals in biochar. The pH value was highest in soils treated with 10 t ha^{-1} biochar and lowest value was recorded in control plot (Nigussie *et al.,* 2012; Southavong *et al.,* 2012).

Application of prosopis biochar with 10 per cent dose in pot culture study revealed that, soil pH was significantly increased to 10.9 compared to control (8.0). The increase in pH could be due to alkaline nature of biochar material added influenced pH of the soil (Kaur and Sharma, 2015). The surface of biochar contains oxygen active groups like $COOH^-$ or OH^- and these react with metal cations and H^+ ions present in the soil resulted change in soil pH (Gan *et al.,* 2015).

Liu and Zhang (2012) reported that increase in biochar application rate results in higher CEC that control soil salinization process in agricultural fields. The highest pH (6.33) and EC (0.42 dSm^{-1}) was recorded by the application of prosopis biochar @ 5 t ha^{-1} followed by cotton stalk biochar @ 5 t ha^{-1} (pH: 6.30 and EC: 0.35). The increase in soil pH in the biochar applied soil was primarily due to the alkaline pH (8.4– 10.8) of biochar (Pandian *et al.,* 2016). Biochar application in acidic soil results in increased soil pH that influences availability of macro and micro nutrients, which in turn increased the pod yield of groundnut. In acid soil, biochar application of 10 t ha^{-1}significantly increased soil pH from 4.62 to 5.87 and reduced the negative effect of Al (Wisnubroto *et al.,* 2017). Song *et al.,* (2014) observed that addition of cotton biochar at 5 t ha^{-1} does not have any impact on the pH of the alkaline soil.

In incubation study conducted by Wang and Gao (2015) reported that the soil pH showed an increase trend with the increased rate of maize straw biochar addition during the study period of 90 days. This confirmed that the biochar can be used as amendment for reclaiming acid soils due to its higher pH.

Cation exchange capacity

The oxygen active groups present on surface of biochar are negatively charged and thus results higher CEC of biochar. CEC is an essential indicator of soil quality and soil amended with biochar increased soil CEC. A higher CEC of soil shows high capacity for nutrient fixation, which is highly essential for plant growth.

Viger *et al.,* (2015) observed that the CEC plays major role in retaining and exchange of ions with its environment that includes microorganisms and plant roots. Biochar retain applied nutrients and provides to growing plants thereby minimizing the waste. Peng *et al.,* (2011) inferred that incubation of rice straw derived biochar @ 2.4 t ha^{-1} for 11 days increased soil CEC from 4 to 17 per cent, reduction of aggregate stability from 1 to 17 per cent and improved the dry matter yield in maize crop.

Carvalho *et al.,* (2014) concluded that biochar application increased CEC, organic carbon content, in turn improved soil structure and reduction soil N_2O emission. In addition, it also improved available phosphorus, exchangeable cations and CEC in biochar treated soils (Kamara *et al.,* 2015). Pandian *et al.,* (2016) stated that application redgram stalk biochar @ 5 t ha^{-1} registered maximum CEC of 6.5 cmol kg^{-1}. Biochar addition in the ratio of 1:100 increased soils CEC by 0.92 cmol kg^{-1}over control and CEC keeps on increased with the additional dose of biochar (Tan *et al.,* 2017).

Study conducted by Alburquerque *et al.,* (2014) showed that high CEC of the soil did not increase when biochar applied at different rates and the soil type used for conducting experiment was rich in sulphate (SO_4^-) and chloride (Cl^-) anions.

Biological properties

Influence on microbial population

Rondon *et al.,* (2007) reported that the addition biochar improved availability of boron and molybdenum that results in higher Biological Nitrogen Fixation (BNF) with common bean (*Phaseolus vulgaris*). Higher pH and less N availability along with increase in K, Ca and P availability might also have contributed to nitrogen fixation. Bean yield increased by 46 per cent and biomass production by 39 per cent in biochar added plots.

Warnock *et al.,* (2007) pointed out that biochar addition influenced soil microbial populations and soil biogeochemistry. Biochar with symbiotic mycorrhizal association in soil ecosystem benefited ecosystem restoration, carbon sequestration resulting in sustainable plant production. Biochar is an superior organic manure for increasing soil organic carbon, retention of water and shelter for microbes (Mankasingh *et al.,* (2011).

Incorporation of biochar in the soil significantly increased the microbial efficiency, basal respiration and microbial biomass carbon (Steiner *et al.,* 2008). Kolb *et al.,* (2009) found that, biochar addition influenced the soil microbial biomass, activity and nutrient availability. The porous nature of biochar provides a safe habitat for many microorganisms such as mycorrhizal fungi, actinomycetes and bacteria. It helps to grow the microbial populations that benefits for plant growth (Lehmann *et al.,* 2009). The pore space of biochar provided habitat for soil organism and protected from predators (Warnock *et al.,* 2010).

Meng *et al.,* (2013) claimed that addition of biochar, helps for the development and reproduction of microbes through supplying carbon, energy sources and mineral nutrition by retaining higher amount of moisture and improvement in soil quality. Lin *et al.,* (2012) concluded that organic carbon and mineral nutrients are stored in the porous structure of biochar that influence soil microbial population and activity. The soil microbial biomass varied with the source of biochar used for preparation, soil texture and other soil ecosystem.

Anders *et al.,* (2013) revealed that higher carbon and nutrient availability was increased due to biochar application or indirectly through activity of plant root thereby increase in soil microbial biomass. Abbas *et al.,* (2017) opined that biochar addition increased the microbial population, specifically more number of bacterial colonies could be isolated and characterized which improved soil health and mobilized macro and micro nutrients to plants.

Incubation experiment conducted by Dong *et al.,* (2013) with biochar produced at two different temperature of 350°C and 700°C showed that significant increase in microbial population in the biochar produced at 350°C, while low biological activities in biochar prepared at 700°C . Biochar added to the soil serves as store house for bacteria and AM fungi that mobilize soil nutrients for plant uptake (Fox *et al.*, 2014). Graber *et al.,* (2010) stated that biochar application increased the population of *Pseudomonas, Mesorhizobium, Brevibacillus, Bacillus*, and *Trichoderma*, which in turn improved conditions in the rhizosphere of the plant for better establishment of crop. Bhattachariya *et al.,* (2017) recorded highest Microbial Biomass Carbon (MBC) was recorded with pine needle biochar @ 2.5 t ha^{-1} in soil after harvest of rice crop. The percentage increase in MBC was 147.2 per cent, 97.6 per cent and 65.7 per cent more over control, wheat residue @ 5.0 t ha^{-1} and lantana residue @ 2.5 t ha^{-1}, respectively. The composition of soil microbial population was significantly changed by addition of biochar (Jiang *et al.*, 2016).

According to Deb *et al.,* (2016) biochar has the ability to increase ammonia and phosphates ions in soil and helped for the growth and multiplication of Phosphorus Solubilizing Microbes (PSM), which solublise and mobilize phosphorus in the soil for better uptake by plant roots. In phosphorus deficient soil, application of biochar along with PSM significantly increased crop yields. Wu *et al.*, (2017) reported that increase in bacterial diversity was observed in biochar added soil and this was correlated with the quantity of biochar. Apart from this, addition of biochar in to the soil increased water holding capacity, enhanced microbial biomass and improvement in bacterial community structure resulted in reduction of nitrogen leaching.

Pandian *et al.,* (2016) observed that the bacteria count was highest (42×10^{-6} CFU) in redgram stalk biochar @ 5 t ha^{-1} applied plots followed by maize stalk biochar @ 2.5 t ha^{-1} (41×10^{-6} CFU). In case of fungal population, higher number of colonies (33×10^{-3}) were recorded in coconut coir pith @ t ha^{-1} followed by redgram stalk biochar @ 2.5 t ha^{-1} (33×10^{-3} CFU). The actinomycetes were higher (30×10^{-4} CFU) in cotton stalk biochar @ 5 t ha^{-1} incorporated plots. Tan *et al.,* (2017) stated that pores present in the biochar facilitate growth, propagation and protection of microbes from unfavourable external environment. It also supply nutrients to microbes for their growth and multiplication.

Enzyme activities

Jin (2010) pointed out this the enzyme alkaline phosphatase was involved in the process of phosphorus mineralization followed by its utilization in soil and the increased rate of biochar ultimately increased the activities of soil alkaline phosphatases, while d-glucosidase activities decreased. Bailey *et al.,* (2011) found that enzyme activities were influenced by interactions of biochar and type of enzymes present in the soil.

Awad *et al.,* (2012) inferred that biochar amended soil promotes enzyme activities related to nitrogen and phosphorus translation and utilization and suppress soil carbon mineralization. Lal (2013) opined that addition of biochar showed significant influence on soil carbon that leads to increased enzyme activities. Chen *et al.,* (2013) concluded that biochar incorporation increased soil pH resulting in higher activities of soil alkaline phosphatase. Rafi *et al.,* (2015) stated that the application of biochar @ 5.0 t ha^{-1} along with 75 per cent RDF + 4 t ha^{-1} FYM increased oil microbial biomass carbon, dehydrogenase enzyme activity and soil organic carbon while reduction in exchangeable aluminium and exchangeable acidity.

The availability of phosphorus might be due to increased activity of alkaline phosphatase enzyme after biochar application (Xiao *et al.,* 2016). Zhu *et al.,* (2017) indicated that addition of wheat straw biochar increased urease activities due to higher absorption p-nitrophenol by biochar breakdown.

Declining soil fertility is not a good indication for the increasing demands for agricultural production. Excess application of synthetic fertilizers along with cultivation of exhaustive crops under mono-cropping system resulted in destruction of soil physico-chemical properties along with soil health and quality. Biochar is a compressed charcoal-like substance produced from crop residues of agricultural fields or industrial by-products which are organic in nature produced through process of pyrolysis. Biochar not just improves the soil fertility but also aids in reduction of offsite pollution. Not just this, biochar increases the retention of applied nutrients further decreasing the leach-out of nutrients to the hydrosphere. In future, application of biochar needs to be addressed in order to facilitate sustainable agricultural practices along with onsite carbon sequestrations.

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