International Journal of Agricultural and Environmental Research
FREE AND OPEN ACCESS
Available online at www.ijaaer.com
ISSN 2414-8245 (Online)
ISSN 2518-6116 (Print)

BIOCHAR: AN INNOVATIVE APPROACH FOR CARBON SEQUESTRATION AND SOIL QUALITY IN SEMIARID AGRICULTURE

MUHAMMAD RIAZ[1*], MUHAMMAD SALEEM ARIF[1], QAISER HUSSAIN[2,3]

[1]*Department of Environmental Sciences & Engineering, Government College University Faisalabad, Pakistan; [2]Department of Soil & Water Conservation, PMAS Arid Agricultural University Rawalpindi, Pakistan; [3]Soil Sciences Department, College of Food & Agricultural Sciences, King Saud University, P.O. Box 2460, Riyadh 11451, Saudi Arabia*
**Corresponding author: e-mail: mr548@ymail.com*

Abstract

Biochar is a carbon (C) rich material produced from pyrolysis of biomass under no or limited supply of oxygen, resistant to decomposition due to recalcitrant nature and encourages long-term C sequestration in agroecosystems. Biochar can be produced from a wide variety of feedstocks ranging from crop residues, wood chips and organic waste. Physico-chemical characteristics of biochar amendments strongly depend on the pyrolysis temperature and duration. Application of biochar to soil offers numerous benefits to soil-plant systems by improving soil nutrient retention, increasing soil water holding capacities, reducing soil nitrous oxide (N_2O) and methane (CH_4) emissions, sustaining soil microbial activity, and ultimately enhancing soil fertility and plant productivity. Soils in arid and semi-arid regions including Pakistan contain low C contents and high temperature, low rainfall and no external soil organic C (SOC) inputs further restricts SOC buildup. Interactions of biochar with native and fresh organic matter determines C sequestration potential since biochar can increase or decrease organic matter decomposition by inducing positive or negative priming effects respectively. A number of studies performed in arid and semi-arid regions of the world demonstrated the additive effects of biochar on soil-plant systems. However, challenges of multiple origin exist to further explore the biochar potential in low SOC soils.

Key words: Biochar, Carbon Sequetration, Soil quality and Arid zone agriculture

INTRODUCTION

Historical background: Biochar is a novel word but it is not a novel material. Biochar has been used in past about from 2000 years in many parts of the world in the form of 'slur and slash' (Hunt et al., 2010; Dennis and Kou). Archeologist searched some area of high quality soil at the end of 19th century in Amazon region, Brazil known as terra preta de Indio (dark soils, black earth) that were developed by local community 'Amerindian population' by adding biochar into soils. Terra pretas are several years old, build up in approximate 4-5 decades and soils may have 0.5-5 meters depth. It is estimated that terra preta soils of onemeter depth per hectare possesses approximately 250 tonnes of carbon as compared to adjoining soils which have 100 tonnes of the same matter. It has been proven that this historical soil has higher concentration of carbon which responsible to improving the soil compositional structure, stimulating the microbial activity, nutrient quality and crop yield as well and leading towards the agroecology in terms of soil fertility and sustainable yield (Winsley, 2007; Ahmad et al., 2013). Biochar addition in agriculture has also been founded in some states of Asia, remarkably Korea and Japan (Hunt et al., 2010).

Biochar: Biochar is like a charcoal (char) consists of enriched carbon, stable organic and recalcitrant material used for soil amendment to achieve sustainable agriculture. Major difference between charcoal (char) and biochar are their application. Charcoal is a solid product, containing less carbon content and retains the properties of the original biomass (feedstock) at temperature above 300 C and utilized as a fuel for heating purposes. Sometimes term char is exchanged with charcoal, less charred substance than charcoal; commonly result of floral fire (Gryze et al., 2010).

Biochar can be defined as stable, recalcitrant organic material that produces in low or zero oxygen level at various temperatures in a controlled condition usually through a technique, pyrolysis. Biochar acts as soil conditioner and increases the fertility and quality of soil by improving soil properties and its processes via enhancing physico-chemical and biological characteristics of soil including enhancing CEC, water and nutrient retention capacity and decline the rate of nutrient deficiency via adsorption, decreased ground water contamination and support microbial activity with some controversies like reduce the bio-accessibility of pesticides undergo helpful in soil functioning via decomposition (Major, 2010). Concurrently, plays vital role in climate change and carbon sequestration in soil. It has capability to remove carbon in the form of CO_2 from atmosphere and store in the soil. It is predicted that phenomenon of carbon sequestration can decline the rate of carbon emissions almost 10% by negative CO_2 emissions globally. Plants have set amount of carbon from atmospheric CO_2 via photosynthetic process once pyrolysis product is incorporated to soil as biochar remains in soil to millennium whereas staying time of fresh crop litter material are about some years (Jeffery et al., 2011; McHenry 2011). It provides labile organic fraction (carbon) in the soil as a priming effect (Zheng et al., 2010). Labile organic carbon is a substance that instantly provides nutrient and energy to soil microbes through mineralization process and makes them available for foliage. Its time period is about days to years and gives little amount of nutrients over the year (Strosser, 2010).

POTENTIAL FEEDSTOCK

Biochar is a heterogeneous material due to wide range of biomass that can be utilized for the production of biochar such as forest waste i.e., tree bark, wood pellets and wood chops; crop residues like wheat straw, corn stover, rice husk, nut shells; switch grass, bamboo and organic waste such as paper pulp, municipal green waste, sawmill waste, manure, sewage sludge, sugarcane bagasse and even human waste. Generation of energy from pyrolysis process depend upon biomass stock and its concentration **(**Clough et al., 2010; Maraseni, 2010; Sohi et al., 2010). Suitability of each biomass depends upon ecological, climatic, fiscal, logistic, physical and chemical factors (Verheijen et al., 2009).

Physicochemical properties of biochar: Physically, biochar is a porous material and has high surface area due to which it inhibits or slows down the process of nutrients leaching by adsorption phenomenon and makes them available for vegetation. Biochar has strong ability to adsorbs toxic materials such as heavy metals like cadmium and arsenic to contaminated soils and as well as manganese and from acidic soils owing to its surface ability that has several chemically reactive groups like ketons, OH, COOH (Berek et al., 2011). It has been proven that biochar declines the rate of nitrous oxide emissions, NH_3 volatilization and nitrogen leaching (Clough et al., 2013). It has high carbon ratio, low mass content and stable due to long chain carbon (aromatic structure), shows persistence due to recalcitrant nature and acts as carbon sink in the soil (Biedermman and Harpole, 2013). Biochar has neutral to alkaline pH, favorable in acidic soil and usually increased the soil pH. Anyhow, biochar production at low temperature can manage the soil pH. All biochar has similar characteristics to some extent. It is sated that physical and chemical composition of biochar depends upon its temperature limits or conditions of pyrolysis and nature of feedstock used (Zheng et al., 2010).

Production of biochar: Numerous thermochemical technologies (gasification, hydrothermal and pyrolysis) are available to produce biochar with the addition of bio-oil (liquid and organic) and syngas (hydrogen, methane and carbon mono oxide and CO_2) as a byproduct. Gasification and hydrothermal practices produces syngas and bio-oil as a primary product and biochar since a secondary product respectively. Significant amount of biochar generates from a thermal decomposition by charring a wide variety of biomass in a complete absence of oxygen or partial presence of air at a range of temperature under controlled condition through a thermochemical process such as pyrolysis (Sohi et al., 2010, Zheng et al., 2010). Pyrolysis is a chemical procedure that transforms degradable organic matter into biochar (biomass charcoal) relatively at range of temperature usually 200 to 900 C; quantity and quality of biochar product depend upon the degree of temperature and characteristics/variety of biomass used (Ahmad et al., 2013). Energy content produces from pyrolysis depending upon the moisture content of biomass.

PYROLYSIS CONDITIONS

Fast pyrolysis: Fast pyrolysis process required approximately 500 °C temperature and its residence time almost is 1 second. Main product of this method is bio- oil (75%), and byproducts are syngas (13%) and biochar (12%) correspondingly.

Intermediate/moderate pyrolysis: This type of pyrolysis follows the above temperature while its residence time is 10-20 seconds. Primary product of moderate pyrolysis is bio-oil (50%), other products are syngas and biochar containing 30 and 20% respectively.

Slow pyrolysis: This is most favourable condition for making biochar since it produces more quantity of biochar than other pyrolysis procedure. Its retention time is 5-30 minutes and follows the above temperature (500 °C). Products of biochar are in such order as biochar ≥ syngas > bio-oil containing 35% ≥ 35% > 30% correspondingly. According to some studies, high amount of biocar nearly 50% produces by using low temperature pyrolysis.

Gasification: Gasification usually required high temperature almost >750 °C and its retention time is about 10-20 seconds. The concentrations of byproducts are evaluated in the following manners like 85% syngas > 10% biochar> 5% bio-oil, respectively.

Energy recovery: The pyrolysis product like bio-oil can be used to attain energy for heating appliances by using internal cumbution engine. Syngas can also be used in energy conversion devices such as fuel cell, gas engines and turbines for electricity generation. Bio-oil and syngas can be 'developed' to bio-diesel as an alternate source of gasoline. However, little work is done in the perspective of electricity production by co-generation technique or energy efficient on practical basis (Joseph et al., 2007; Maraseni, 2010).

Impact of heating temperature on biochar quality: Previous studies have shown that quantity and quality of biochar depend on heating temperature of pyrolysis systems; high temperature reduces the number of biochar and enhances the percentage of bio-oil and syngas as well as increases the ash, organic content, pH value, surface area and porosity whereas concurrently lessens the concentration of labile carbon that is easily decomposed by soil microbes and responsible to increase the fertility of soil and greater temperature increases the value of recalcitrant carbon that is not readily degraded by soil biological organisms. Melo et al. (2013) reported that high pyrolysis temperature (700 °C) decreased the biochar content from 45 to 31% and increased the ash concentration as well as enhance the value of biochar electrical conductivity and pH. In contrast, elevated temperature reduces the rate of cation exchange capacity of biochar owing to the high carbon units and low hydrogen and oxygen concentrations. As a result, lessening the ratio between oxygen and carbon (O/C); and hydrogen and carbon (H/C) and reduction in CEC may happen due to removing oxygen containing functional group. Study determined that low O/C than 0.2 due to recalcitrant nature of biochar in soil. Low temperature produces high amount of biochar and low value of bio-oil and syngas. So, the inconsistency of biochar has various significant effects on health status of agricultural soils. The pyrolysis temperature has significance impact on sorption kinetics of biochar as surface area play critical role in expressing the uptake capacity of essential metals or nutrients by plants (Zheng et al., 2010).

Health hazards associated with biochar production: Various harmful substances like particulate matter especially PM_{10} and carcinogenic compounds (dioxins, PAH) are produced along with biochar production. Dust and high organic product (biochar) may generate problem of fire hazard and spontaneous combustion from thermochemical technologies and create dilemma of chronic diseases such as lung cancer and cardiovascular disorders. Gaseous emissions like CO_2 and CH_4 from pyrolysis systems can be controlled or mitigate by adopting careful planning, policy making and by using modern pyrolysis via firm control on pyrolysis conditions such as temperature and biomass stock. While risks are associated with biochar production, storage and distribution and application rate to soil. Anyhow, the possibility of atmospheric emissions and occupational health hazards are still existed from these technologies (Collison et al., 2009; Verheijen et al., 2009).

Interaction of biochar with fertilizer: It is hypothesized that biochar reduces the requirement of organic and inorganic substances (fertilizers) into soil due to its long-lasting effects on agroecosystem. it is predicted that it can also be used in combination with other suitable substances like compost, manure and commercial fertilizers with respect to soil type, biomass properties and pyrolysis conditions for attaining better outcome in terms of plant biomass and crop production and for managing the soil ecosystem as well in futuristic way. Carter et al., 2013 evaluated that crop biomass was higher in biochar free fertilizer soil in comparison to biochar mixed fertilizer soil. On contrary, it is revealed that nitrogen fertilizer with biochar incorporation gave better biomass and yield in paddy soil than biochar application to soil (Wang et al., 2012). Similar finding is founded by Clough et al. (2013) Beesley et al. (2010) reported that value of soil pH, water soluble carbon and total organic carbon content increased by the application of biochar with compost in slightly acidic soil.

Impact of biochar application on agricultural soils and plant growth: The variability and quality of biochar from pyrolysis systems have various impact on agricultural soils in terms of soil physicochemical, biological and biochemical attributes such as soil structure, nutrient content, water holding capacity, cation exchange capacity (CEC), soil pH, soil fauna such as microbial biomass i.e., biomass activity, microbial biomass carbon, soil respiration and enzymatic activities and soil flora i.e., seed germination, plant growth, plant biomass and crop production. It is hypothesized that biochar enhances the mechanism of sorption capacity of soil such as CEC, water and nutrient holding capacity of soil due to its porous nature and responsible to increase the soil pH and microbial community (Major et al., 2010; Atkinson et al., 2010). The solid and robust data is insufficient on soil resources especially on microbial activity and crop productivity on ground basis due to limiting scientific research, lack of knowledge and heterogeneity among biomass potential, soil type, and environmental or climatic conditions (Jeffery et al., 2011).

Soil texture: The impact of biochar irrigation on soil mainly relies on biochar characteristics, soil texture, environmental condition and variety of plant. Jeffery et al. (2011) reported that biochar amended soils stimulate the crop productivity in medium and coarse soil textures in comparison to fine soil textural class that was very acidic. Statistically, it was determined that biochar application on soil has significance ($p < 0.05$) effect on cultivar yield. Basically, yield depends on soil type, biochar production and nature of crop. So, soil texture is one of most important parameter in biochar application to soil for attaining best benefit.

Soil pH: Biochar application is very effective in acidic and neutral soils that enhanced the value of soil pH as respective substance is itself of alkaline nature (Wang et al., 2012). Agricultural industry of Pakistan has calcareous soils in terms of high concentration of salts and high pH values geographically. Few studies stated that biochar amending soil does not show either positive or negative effects, possibly it may reduce the crop yield but general trend exhibits that crop productivity increases by biochar addition in acidic soil. This is also hypothesized that positive effect of biochar application may retard the plant growth on long term basis (Verheijen et al., 2009). Most studies are conducted in western acidic soils that give promising results with biochar application, while none a single paper is published till now to see the impact of biochar in calcareous soil especially in Pakistan. Carter et al. (2013) reported that biochar derived from rice husk had 7.79 pH, increased the average value of pH of Cambodia soil which was acidic in nature. Anyhow, biochar application significantly ($p < 0.001$) increased the soil pH from 5.5 to 6.1 units combine with fertilizer than soil without organic fertilizer since compost is also increased the soil pH. It was recorded that plant biomass was higher in biochar amended free fertilizer soil. Increase in soil pH by biochar application, ranging from very acidic to neutral soil is also agreed by Jeffery et al. (2011). A similar finding is also received by Beesley et al. (2010) in slightly acidic soils by biochar application along with compos from 5.45 to 7.56 units. Another incubation study of 22 weeks described by Chintala et al. (2014) that biochar produced from corn stover and switch grass improved the pH and electrical conductivity of acidic soil at four concentrations of 0, 52, 104, and 156 mg/ ha at 650 C paralyzed temperature. Soil received biochar from corn stover had significant effects ($p<0.05$) on soil EC and pH at all concentrations as compared to soil irrigated with switch grass. Various studies described that biochar addition in acidic soil responsible to increase the pH value of soil (Atkinson et al., 2010, Major et al., 2010, Zwieten et al., 2010).

In contrast, Shenbagavalli and Mahimairaja, (2012) founded that biochar application reduced the soil pH (8.42- 7.92) with increasing concentration of biochar (0-5%) at the end of 90 days of soil simulation study. This may include some factors like production of acid producing soil microbes that degrade the organic nutrients into organic acid and it may be due to the hydrogen ions that releases from biochar exchangeable sites. Some studies supported that low pH biochar can decline the rate of pH that would be very effective in calcareous soil.

Sorption capacity (Soil water and nutrient holding capacity): Biochar has capability to interact with soil physical and chemical elements owing to the large surface area, high porosity and charge density (Biedermman and Harpole, 2013). It is documented that biochar has capability to increase the water and nutrient holding capacity of soil due to sorption capacity that support plant biomass and cultivar yield by improving soil eration and aggregation in fine soil type. Further research was needed to investigate the workability of biochar on sorption capacity in calcareous soil (Collison et al., 2009; Shenbagavalli and Mahimairaja, 2012). CEC of freshly added organic matter is relatively low, having low porosity and particle size distribution than old biochar. Fresh biochar has affinity to compact the soil and increase the rate of water runoff due to water repellency of biochar. It has been proven that biochar declines the rate of nitrous oxide emissions, NH_3 volatilization and nitrogen leaching by immobilization and concurrently increases the rate of nitrogen fixation by biological organisms (Clough et al., 2013).

Biochar has significance effect on the cation exchange capacity (CEC) of soils that plays vital role in soil reaction. Phenomenon of nutrients or mineral particles like adsorption, desorption and their availability to plants are generally associated to cation exchange capacity of soil that dependent on soil pH and concentration of organic matter. It is documented that cation ion exchange capacity of soil increases with increasing pH values (Atkinson et al., 2010). Carter et al., 2013 determined that biochar increased the sorption capacity of Ca, Mg, K and trace elements like aluminum (Al), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni), silicon (Si) and Zinc (Zn) etc. It is texted that these trace metals may stimulate the crop biomass but single influence of these metals on crop productivity are not known, need to be further studied to address the impact. Zwieten et al. (2010) reported that biochar amended soil increased the level of CEC and as well as enhanced the rate of exchangeable calcium ion in ferrosol and potassium ions in calcareous soil. Another incubation study of 22 weeks described by Chintala et al. (2014) that biochar produced from corn stover and switch grass improve the pH and electrical conductivity of acidic soil at four concentrations of 0, 52, 104, and 156 mg/ ha at 650 C paralyzed temperature. Soil received biochar from corn stover had significant effects ($p < 0.05$) on soil EC and pH at all concentrations as compared to soil irrigated to switch grass. It is determined that biochar amended soil has great impact on soil sorption processes and fate of organic compounds such as pesticides. It was observed that diuron a herbicide has high sorption capacity in loamy soil (Yang and Sheng, 2003). There is a wide gap of association between biochar and complex organic compounds like pesticides, time to explore the fate of complex organo molecules in agricultural soils.

Soil nitrogen dynamics: Nitrogen is a limiting factor for plant growth in soil environment. Nitrogen is present in a complex oraganic forms that must be transformed into NH_4^+ and NO_3^- before uptake to plants. Biochar addition into soil may have significant effect on soil nitrogen mineralization processes such as "ammonification and nitrification" and as well as denitrification and nitrogen fixation processes (DeLuca et al., 2009). Various studies have been carried out to determine the impact of biochar application on soil nitrogen dynamics in terms of nitrate leaching, nitrous oxide emission, immobilisation and biological nitrogen fixation as well. The phenomenon of nitrate adsorption mainly depends upon biochar feedstocks and pyrolysis temperature, soil type and biological nitrogen demand. It is revealed from literature that nitrate leaching significantly depend on the nitrate adsorption capacity in biochar amended soil. Some studies described that meso and micro pore spaces in soil increased the hydraulic conductivity of biochar amending soil that cause nitrate infiltration. In contrast, water holding capacity of soil usually retains the nitrate and reducing the rate of leaching. Problem of leaching could be mitigated or managed by calculating the value of water holding capacity, biochar characteristics and suitable rate of biochar application to soil (Clough et al., 2013). It is concluded from various results that NO_3^- are weakly bonded with biochar surface and has great chances to leach down. So, it can be removed or uptake by plants during their retention time. It was also studied in some experiments that low temperature biochar have greater quality to immobilize the nitrate and decreased the rate of leaching by increasing retention time and as a result enhanced the rate of net nitrification. Fate of NH_4^+ adsorption with biochar has been evaluated in many studies either could be uptake by plants or removed from soil. Charred biomass has high CEC and retention time than fresh biochar, anyhow, rate of immobilization of NH_4^+ with fresh biochar in long term experiment required further research to know the impact on net nitrogen immobilization.

Biochar adding soil decreases the nitrogen mineralization in comparision to fresh biochar. It is reported that slow pyrolysis product enhanced the net N mineralization and fast pyrolysis product increased the immobilization of mineral-N in nine-month study. Biochar has capability to reduce the nitrous oxide emission from soil (Wang et al., 2012; Mukherjee and Lal 2013). But fluctuation in N_2O emissions may be likely owing to the number of reasons like rate of nitrogen emission from biochar, priming effects with SOM, soil water retention, denitrification and nitrogen fixation process and substrate availability (inorganic nitrogen and or carbon compound) to microorganisms (Wang et al., 2012).

Soil carbon dynamics: Primarily, there are three main categories of soil organic matter involving labile, stable and inert fraction (Strosser, 2010). Carbon is not directly utilized by plants but plays a vital role in biogeochemical processes to improve the soil structure. Biochar is a source of carbon and its application to soil enhance the concentration of organic carbon in farming culture. Biochar has capability to remove carbon from atmosphere and sequester them into soils to thousands of years. Biochar is a "win-win approach" in terms of attaining sustainable yield and mitigating the climate change by storing carbon into soil (Krull, 2010). The phenomenon of carbon sequestration depends on the types of biomass, soil structure, land management, plants cultivation and climatic conditions such as precipitation rate and temperature. Biochar application usually acts as soil conditioner in place of fertilizer in agriculture soil (McHenry 2011). It has been supposed at long time that soil organic nutrient and biological diversity are significantly correlated, while evidence on practical basis is limited. This area of interaction with biochar is unseen yet as biochar has interaction with soil minerals than organic matter. There is no fact that biochar adding soil has direct impact on microbial population. Since, there is a lack of knowledge and gap between the association of biochar with soil biological community in terms of meso and macrofauna of soil (Verheijen et al., 2009).

SOIL BIOTA

Currently, biochar addition to soil has insufficient data and lack of publication about its mobility and or fate in the soil profile as each layer has varied amount of oxygen for oxidation of biochar and microbial activity.

Soil microorganisms: Soil microbes play vital role in biogeochemical processes, biodegradation, immobilization of substances and responsible to ameliorate the soil structure via enhancing soil porosity and reducing the rate of leaching that lead towards soil fertility and quality to gain net yield. Biochar application into soil may change the biological status of soil such as microbial activity and their processes in terms of microbial biomass carbon, nitrogen and phosphorus; microbial respiration and function of enzymes. It was investigated that biochar is an inert material that slowly biodegraded over several years. It is supposed that biochar itself may not play considerable effect on soil biology due to its recalcitrant nature but it has significant effect on soil minerals. Anyhow, surface material (biochar) adsorbs the remaining of bio-oil or other organic material/glucose source that serves as labile carbon and increases the rate of microbial activity and stimulates the concentration of biodegradation in short term. Degradation of easily available carbon (labile carbon pool) may initiate the process of co-metabolism with aged biochar during simulation study. Amount and composition of biochar may directly or indirectly affect the biological properties of soil (Thies and Rillig, 2012).

Researcher explored the biological status in terra preta soils that was remarkably distinct to surrounding soils and significantly have higher concentration of microbial biomass such as number of fungi and bacteria, presented higher metabolic rate and low rate of microbial respiration which lead towards the stabilization and storage of organic nutrient in Amazon basin with time. Low rate of microbial respiration possibly may be act as primary driving mechanism like chemisorptions of evolved CO_2 to the biochar surface, need to be resolved.

It is reviewed by Thies and Rillig (2012) by from previous literature that soil biological populations are basically comprises of range of biomass involving fungi, bacteria, archaea, protozoa, algae, arthropods, nematodes and invertebrates like earthworm. Biochar amended soil develops a complex mechanism with physicochemical, biological and biochemical attributes of soil and responsible to changing the soil compositional structure such as organic and inorganic soil nutrients, pH units and enzymatic pathway and ultimately effect of these attributes is on soil microbial population, biomass richness, variation and their allocation in soil ecology.

It is assumed that biochar amended soil increases the adsorption of inorganic substances, water soluble organic carbon, toxic material including heavy metals, secondary toxic compounds or metabolites, pesticides and gases that have significant effect on microbial population, biomass, variations and their functions. Binding of substrate and microbes to the biochar surfaces may stimulate the biodegradation rate due to high amount of carbon source availability to microorganisms specifically bacteria, arbuscular mycorrhizal fungi and blue green algae (actinomycetes). Little literature was revealed that biochar adding soil stimulates the arbuscular mycchorizal fungi for plant growth and suitable place for microbes for reproduction and growth. But in some instances, it might not be happened owing to the inaccessibility of substrate that present in the layer of clay soil type like montmorillonite. Porosity and pore size distribution of biochar provide a locality to microbes that prevent them from predator and other harmful episodes. Adsorption of biochar dwelling microbes to substrate would enhance the immobilization rate or it only act as shelter to prevent them from victimize is unknown yet, required further investigation to undo the hidden facts.

Bacteria exist preferably in neutral soil pH as compared to acidic and basic soil, while fungi can survive at high pH. In this scenario, biochar can alter the population of microbes from bacterial to fungal ratio and metabolic pathway of enzymes, need to be further explored. Extracellular enzymes of bacteria and fungi decompose the organic compounds that release from surfaces of biochar, organic matter, mineral particles like clay; plant roots and soil aggregates. Now, it is time to elaborate the role of the various biochar constituents with the extracellular enzyme activities of microbes.

The interaction of biochar in soil with minerals particles, inorganic substances and biological organisms are complex and required further solid and robust research to know the direct impacts of biochar on soil microorganisms in terms of interaction of biochar surface with microbial capsular materials and cell walls as well as to evaluate the indirect impacts by adsorption of various toxic compounds, gases and organic and inorganic particles with biochar product. It is documented that culturable bacterial populations were found in the terre prete soils at 1-meter depth than adjoining soils (Ritz, 2007). Biochar along with organic fertilizer activate the N_2 fixation by both free living and symbiotic diazotrophs. Higher N_2 fixation was recorded, 30-40%, in mung bean yield at 50 g kg^{-1} application rate (Rondon et al., 2007). Application rates of biochar higher than 67 tons ha^{-1} from poultry manure have a harmful impact on earthworm subsistence likely may be due to higher concentration of salt or alkaline soil. Variability of biochar may have various influences on the soil organisms like earth worm showed high efficiency in pine chip biochar in comparison to biochar with poultry manure (Verheijen et al., 2009).

There is no research has been conducted yet to know the effects of biochar amending soil on soil microarthropods such as collembola or acari, or on other soil organisms such as rotifers and tardigrades and these organisms can be depressed by Biochar contamination. There is not a single research undertaken to investigate the effects of biochar on soil megafauna such as badgers, moles or other vertebrates. It may be possible that soil megafauna affected by ingestion and or inhalation the biochar scraps and dust particles respectively. Anyhow, there is not yet research evaluated to identify the effect of biochar on the respiration processes of soil megafauna (Verheijen et al., 2009).

IMPACT OF BIOCHAR APPLICATION ON CROP PRODUCTIVITY

Several studies indicated that biochar application enhanced the crop yield and biomass above ground most commonly in ferrosol (acidic soil) (Major et al., 2010). Jeffery et al. (2011) evaluated the effect of biochar amending soil on crop yield in the light of previous studies by using meta-analysis and reported that biochar amended soil increased the crop productivity; greater significant effects were observed in acidic soil followed by natural soil in the order of 14% > 13%, positive effects were also recorded in coarse soil textural class. Significance results may attain probably owing to the water and nutrient retention capacity and liming effect with biochar addition as well at 100 tons ha^{-1} of biochar application into soils. Statistical analysis showed that biochar produced from poultry manure enhanced crop yield more like 28% than biosolids. It was also determined by Carter et al., 2013 that biochar application stimulated the crop biomass in acidic soil. Zwieten et al. (2010) determined that biochar application along with fertilizer in acidic soil gave better outcomes than calcareous soil due to its liming effect. It was observed that germination percentage of wheat crop increased at 100% biochar application rate in low pH soil than high pH soil. It also improved the weight of soybean and radish in acidic soil along with fertilizer, while alkaline soil increased the soybean weight and reduced the radish and wheat mass. Carter et al., 2013 reported that biochar produced from rice husk have significant effect on lettuce and cabbage crops by heightening the morphological status and biomass in acidic and sandy soil. It is exhibited that hardwood biochars along with poultry dung generally stimulate the crop production (Clough et al., 2013). The optimal gain of biochar incorporation has reported in western acidic soils that reduce soil pH and retain the nutrients and provide better yield (McHenry, 2011). Biochar has positive significance effects on various cultivars at controlled condition in short term studies, now time to explore the impact of biochar on plant biomass and yield in long term studies or practically in field rather than pot trials or incubation studies (Sohi et al., 2009).

CONCLUSIONS AND FUTURE PERSPECTIVES

The incorporation of biochar to soil has number of benefits in agricultural soils by ameliorating the soil structure via enhancing the rate of soil pH, water and nutrient holding capacity of soil and reducing the leaching process of nutrients specifically nitrogen, phosphorus and trace elements via adsorption and minimize soil acidity, exchangeable Al, reduce the greenhouse gas emissions and combat the climate change by sequestering carbon from atmosphere as negative gaseous emissions.

The application of biochar into soil is necessary not luxury owing to the rapid soil degradation by massive land uses due to urbanization and fulfill the demand of increasing population in a sustainable way. Biochar amended soil is relative infancy and young area of study, have many gaps and little knowledge due to limiting scientific research, research facilities especially in the context of biological activity and need further investigation to explore biological health status of agricultural soil in all types of soil particularly calcareous soil in long term basis for sustaining agroecosystem.

REFERENCES

Ahmad, M., Rajapaksha, A.U., Lim, J.E., Zhang, M., Bolan, N., Mohan, D., Vithanage, M., Lee, S.S., & OK, Y.S. (2013) Biochar as a sorbent for contaminant management in soil and water: Areview. *Chemosphere*, 1-15

Atkinson, C.J., Fitzgerald, J.D. & Hipps, N.A (2010) Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review. *Plant Soil*, 337:1–18

Beesley, L., Moreno-Jiménez, E. & Gomez-EYLES, J.L. (2010) Effects of biochar and greenwaste compost amendments on mobility, bioavailability and toxicity of inorganic and organic contaminants in a multi-element polluted soil. *Environmental Pollution,* 158: 2282-2287

Berek, A.K., Hue, N. and Ahmad, A. (2011) Beneficial Use of Biochar to Correct Soil Acidity. *The Food Provider, 1-3.*

Biederman, L.A. & Harpole, W.S. (2013) Biochar and its effects on plant productivity and nutrient cycling: a meta analysis. *Bioenergy*, 5, 202-214

Brown, R. (2009) Biochar Production Technology, in Lehmann, J. and Joseph, S. (eds), (2009) Biochar for Environmental Management: Science and Technology. *Earthscan*, London, UK.

Carter, S., Shackley, S., Sohi, S., Suy, T.B. & Haefele, S. (2013) The Impact of Biochar Application on Soil Properties and Plant Growth of Pot Grown Lettuce (*Lactuca sativa*) and Cabbage (*Brassica chinensis*). *GCB Agronomy, 3*, 404-418.

Chintala,R., Mollinedo, J., Schumacher, T.E., Malo, D.D. & Julson, J.L. (2014) Effect of Biochar on Chemical Properties of Acidic Soil.

Archives of Agronomy and Soil Science, 60(3), 393-404

Clough, T.J., Condron, L.M., Kammann, C., & Müller, C. (2010) A Review of Biochar and Soil Nitrogen Dynamics. *Agronomy, 3*, 275-293

Collison, M., Collison, L., Sakrabani, D.R., Tofield, D.B., Wallage, D.Z. (2009) Biochar and Carbon Sequestration: A Regional Perspective A report prepared for East of England Development Agency (EEDA)

Deluca, T.H., Mackenzie, M.D. & Gundale, M.J. (2009) Biochar Effects on Soil Nutrient Transformations. *Biochar for Environmental management, 15(43), 251-270*

Dennis, J. & Kou, K.C.S. Osdp Project # I-150 Final Report. Centre for Sustainable Food Systems at UBC Farm,Vancouver, British Columbia in partnership with Fraser Common Farm Cooperative

Gryze, S.D. & Cullen, M. (2010) Evaluation of the Opportunities for Generating Carbon Offsets from Soil Sequestration of Biochar. *An issues paper commissioned by the Climate Action Reserve* slie Durschinger, pp 1-99

Hunt, J., Ponte, M.D., Sato, D.S., & Kawabata, A. (2010) The Basics of Biochar : A Natural Soil Amendment. *Soil and Crop Management*, 1-6

Jeffery. S., Verheijen, F.G.A., Velde, M. Van Der, Bastos, A.C. (2011) A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. *Agriculture, Ecosystems and Environment,* 144:175–187

Joseph, S.D., Downie, A., Munroe, P., Crosky, A. & Lehmann, J. (2007) Biochar for Carbon Sequestration, Reduction of Greenhouse Gas Emissions and Enhancement of Soil Fertility; A Review of the Materials Science Proceedings of the Australian Combustion Symposium December 9-11, University of Sydney

Krull, E. (2010) From source to sink – A national initiative for biochar research. 19th World Congress of Soil Science, Soil Solutions for a Changing World1 – 6 August 2010, Brisbane, Australia.

MAJOR, J. (2010) Guidelines on Practical Aspects of Biochar Application to Field Soil in Various Soil Management Systems. International Biochar Initiative.1-23

Major, J., Rondon, M., Molina, D., Riha, S.J. & Lehmann, J. (2010) Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. *Plant Soil*, 333:117–128

Maraseni, T.N. (2010) Biochar: maximising the benefits. *International Journal of Environmental Studies,* 67(3), 319–327

Mchenry, M.P. ((2011): Soil Organic Carbon, Biochar, and Applicable Research Results for Increasing Farm Productivity under Australian Agricultural Conditions, *Communications in Soil Science and Plant Analysis*, 42(10), 1187-1199

Melo, L.C.A., Coscione, C.R., Abreu, C.A., Puga, A.P. & Camargo, O.A. (2013) Influence of Pyrolysis Temperature on Cadmium and Zinc Sorption Capacity of Sugar Cane Straw- Derived Biochar. *BioResources*, 8(24), 4992-5004

Mukherjee, A. & LAL, R. (2013) Biochar Impacts on Soil Physical Properties and Greenhouse Gas Emissions. *Agronomy 3*,313-339

Ritz, K. (2007) The plate debate: cultivable communities have no utility in contemporary environmental microbial ecology. *FEMS Microbiology Ecology,* 60: 358-362.

Rondon, M.A., Lehmann, J., Ramírez, J. & Hurtado, M. (2007) Biological nitrogen fixation by common beans *(Phaseolus vulgaris L.)* increases with bio-char additions. *Biology and Fertility of Soils,* 43(6), 699-708.

Shenbagavalli, S. & Mahimairaja, S. (2012) Characterization and Effect of Biochar on Nitrogen and Carbon Dynamics in Soil. *I.J.A.B.R.,* 2(2), 249-255

Sohi, S.P., Krull, E., Lopez-Capel, E., & BOL, R. (2010) A Review of Biochar and Its Use and Function in Soil. *Advances in Agronomy*, 105: 47-82

Strosser, E. (2010) Methods for determination of labile soil organic matter: An overview. *Journal of Agrobiology*, 27(2): 49–60

Thies, J.E. & Rillig, M.C, 2012 Characteristics of Biochar: Biological Properties. 85-102 (eds.) LEHMANN, J. & JOSEPH**, S.** Biochar for Environmental Management. *Science and technology,34-449*

Verheijen, F.G.A., Jeffery, S., BASTOS, A.C., Van Der Velde, M., & Diafas, I. (2009). Biochar Application to Soils - A Critical Scientific Review of Effects on Soil Properties, Processes and Functions. EUR 24099 EN, Office for the Official Publications of the European Communities, Luxembourg, 149pp.

Wang, J., Pan, X., Liu, Y., Zhang, X. & Xiong, Z. (2012) Effects of biochar amendment in two soils on greenhouse gas emissions and crop production. *Plant Soil*, 1-12

Winsley, P. (2007) Biochar and bioenergy production for climate change mitigation *New Zealand Science Review, 64 (1),* 5-10

Yang, Y. & Sheng, G. (2003) Enhanced pesticide sorption by soils containing particulate matter from crop residue burns. *Environmental Science and Technology* 37: 3635-3639.
Zheng, W., Sharma, B.K. & Rajagopalan, N. (2010) Using Biochar as a Soil Amendment for Sustainable Agriculture. Illinois Sustainable Technology Center. University of Illinois at Urbana-Champaign
Zwieten, L.V., Kimber, S., Morris, S., Chan, K.Y., Downie, A., Rust, J., S. Joseph, S. & Cowie, A. (2010) Effects of biochar from slow pyrolysis of papermill waste. *Plant Soil*, 327:235–246