



Review

Biosurfactants-Biochar Facilitated Bioremediation of Metal Contaminated Sites: A New era of Sustainable Development

Rabail Zulekha¹, Riaz Bibi², Zulfiqar Ahmad*³, Azhar Hussian⁴, Aslam Farooqi⁵, Shaista Andleeb⁶

¹*Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad 3804, Pakistan*

²*Gwangju Institute of Science and Technology, Gwangju, South Korea*

³*Key Laboratory for Algal Biology, Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan 430072, China*

⁴*Department of Soil Science, University College of Agriculture & Environmental Sciences, The Islamia University of Bahawalpur, 63100-Pakistan*

⁵*Department of Entomology, UCA & ES, The Islamia University of Bahawalpur, Bahawalpur, 63100, Pakistan*

⁶*School of Resources and Environmental Engineering, Wuhan University of Technology, Wuhan, Hubei, 4300723, China*



****Corresponding author***

Key Laboratory for Algal Biology, Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan 430072, China

Tel: +8613477017156; Email: zulfiqar@ihb.ac.cn; imzulfiqarahmad@gmail.com (Z. Ahmad)

Accepted: 8 April, 2020; ***Online:*** 13 April, 2020

DOI : <https://doi.org/10.5281/zenodo.3750241>

Abstract: Anthropogenic activities result in a high quantity of extraction and use of heavy metals. Heavy metals cannot be degraded and hence accumulated in environment, which in turn threatens the soil quality, plants survival and human health. Remediation of heavy metals deserves attention as it is a serious environmental issue but it is impaired the cost of these technologies. Application of biochar for remediation of such processes may provide a new solution. Efficient metal removal from soil matrix involves use of biosurfactants which subsequently help in adsorption and metals remediation by microorganisms immobilized on biochar. This review provides a state of the scientific research on biochar, its production processes, feeds tock condition and application in remediation of metal contaminate sites. As efficiency of this technology is enhanced to 100% removal, according to our present state of knowledge, this would be the first review which

addresses the biosurfactants assisted bioremediation by using immobilized microorganism technology. Further research directions are identified to ensure a safe and sustainable use of biochar as a soil amendment for remediation of heavy metals contaminated soils.

Keywords: Biochar, Biosurfactants, Heavy metals, Bioremediation, Microbial immobilized cell technology

Introduction

Soil is most primary source for agronomic practices. It serves as main media for crop growth, sustains plant and animal productivity, maintains and increases the quality of air and water as well as supports human health and habitation (Zhou and Song, 2004). Soil quality is threatened by anthropogenic activities. Currently, a significant amount of soils is world widely contaminated with inorganic and organic pollutants due to emissions of waste from industries, mining, manures and bio-solids, use of waste water to irrigate and inappropriate management of chemicals and fertilizer in agricultural practices (Mench et al. 2010). These pollutants are injurious to ecologies and agronomic production and induce in a severe risk to humanoid security as well. Ecofriendly options to unjustifiable management of waste technologies are pursued for reducing soil contamination (Beesley et al. 2011). Extensive struggles are made to amend contaminated territories (Naidu et al. 2008). Many chemical and physical techniques have been developed for treating soil contamination. They comprise of soil vapor extraction, soil washing, land- ion exchanges farming, soil flushing, bioremediation, phytoremediation, and ecological remediation (Zhou and Song, 2004) and combined remediation (Lee et al. 2008). Pollutants degradation procedures can be simplified by biological action in soil, the technique used to degrade soil contaminant is called as bioremediation.

The efficiency of bioremediation practices can be amplified by adding particular improvements to soil (Quilty and Cattle, 2011). Though these are traditional procedures and when we apply in situ these are commonly costly and generate new difficulties, like loss of soil fertility and erosion of soil (Kumpiene et al. 2008). Yet the usefulness of bioremediation on metal adulteration is not so strong and needs alternative way. Hence, new alternatives are searched for removal of the contaminants (Sun et al. 2012). Currently great consideration is being given to biochar as a soil conditioner due to its specific characters and physicochemical features. Carbon-based matter of biochar has stated to be more than 90%, reliant on basis material (Yin and Xu, 2009). Biochar could possibly be part of a long-term adaptation strategy, as it could improve soil physical properties including the increase of porosity and water storage capacity, as well as the

decrease of bulk density (Lu et al. 2014; Nelissen et al. 2015). Potential uses of biochar include carbon repositioning, soil fertility improvement, remediation of different types of pollution and recycling of agronomic waste.

Biochar is the solid substance made from pyrolysis of waste biomass from agronomic practices and forestry manufacture (Wang et al. 2010; Liu et al. 2011; Xu et al. 2013). Soil biochar amendment is thought to have excessive potential in increasing the recalcitrant carbon pool of soil as most carbon in biochar is of fragment arrangement and unmanageable in the surroundings (Lehmann 2007). Naturally, biochar has high pH and cation exchange capacity and has potential to enhance soil production (Jeffery et al. 2011) and high capability to adsorb contaminants (Beesley et al. 2011; Yuan and Xu, 2011). Biochar soil amendment has double profits of carbon sequestration and soil improvement (Lal 2009; Tenenbaum, 2009). It is assumed that the C sequestration capacity of biochar as a viable tool of climate change extenuation known (Molina et al. 2009) is equal to 12% of anthropogenic greenhouse gas emissions (Woolf et al. 2010).

2. Biochar production and properties

2.1 Feed stocks

Conventionally term feedstock is used for biomass that is pyrolysed and changed into biochar. In literature, any organic raw material can be pyrolysed; though the production of compact remains (char) corresponding to fluid and gas yield differs greatly along with physico-chemical features of the resultant biochar. Feedstock and pyrolysis conditions are the most vital features that control the characters of the resulting biochar. The chemical and physical arrangement of feedstock relays to the chemical and structural composition of the resultant biochar and, so are revealed in its activities, role and providence in soils (Brown et al. 2009). An extensive range of waste biomass resources (wood, manure, rice husk, sewage sludge, municipal waste) is be used to make biochar (Maiti et al. 2006; Sohi et al. 2009). A diverse range of supplies is suggested as biomass as raw material to produce biochar, comprising grain husks, wood, nut shells, compost and crop remains, although with the premier carbon concentrations are (e.g. wood, nut shells), plenty and lesser accompanying prices are presently used to produce stimulated carbon (Martinez et al. 2006; González et al. 2009). Other raw materials are possibly accessible for biochar manufacture, of those bio waste (e.g. manure slurry, community waste, chicken litter) and dung. However, a danger is related with usage of such source materials, generally connected to the existence of harmful constituents (e.g. organic pollutants, heavy metals). Great concentrations of calcium carbonate

(CaCO₃) are found in pulp and paper slurry (Van Zwieten et al. 2007) and are retained in the ash part of some biochars.

Complete narration of all biochar raw materials is a far from the space of this review and feed stocks have been studied in other investigations (Collison et al. 2009; Lehmann and Joseph, 2009). The main fact is that the appropriateness of each biomass form as a possible supply for biochar is reliant on mostly biochemical, physical, ecological, as well as commercial and logistical factors (Collison et al. 2009). Biochar is made by pyrolysis ('pyro' in Greek means fire, while 'lysis' means breaking down into constituent parts). Charcoal has been produced from pyrolysis of (woody) biomass for thousands of years, and recently the technology has also become interesting for use in the production of biochar (Laird, et al. 2009). Mainly wood is made up of cellulose, hemicelluloses and lignin. Though all types of wood differ in chemical configuration, so lignin structure present in soft wood varies from hardwood (Windeisen and Wegener, 2008). Normally biochar is made from pyrolysis of the biomass. Pyrolysis permits to produce biochar by heating system with principally minute to absence of oxygen. Anaerobic thermal change of biomass is accomplished in three different methods: pyrolysis/ carbonization; gasification; and liquefaction. All these processes give products in three stages, solid, liquid and gas, and composition of the product depends on procedure situations. Therefore, pyrolysis is regarded as by long habitation times and modest temperatures, liquefaction happens under high heating rates, while gasification is defined by high temperatures, frequently with extra, however sub-stoichiometric, oxygen (Aglevor *et al.* 2010).

Biomass pyrolysis is a very ancient knowledge, which is related to produce energy and convert biomass conversion of biomass (Antal and Gronli, 2003). For thousands of years' charcoal is made from pyrolysis of (woody) biomass, and currently this skill has become stimulating to produce biochar (Laird et al. 2009). Pyrolysis could be done in a reactor by gasification or carbonization at different temperatures and time conditional on the planned usage of the end product. In the course of heating, there are bulk damages, chemical conversions and physical variations, which mostly are influenced by the period of heating, original moistness, wood species and temperature of action. Practically every form of biological material can be pyrolyzed; though both energy change effectiveness and the superiority of the bio-oil, biochar and syngas co-products depend on the nature of the feedstock. The ultimate current transformation of feed stocks produces three basic products; fluid (liquid hydrocarbon and water), solid (biochar) and gas (Karagöz et al.

2005). Feedstock, comprising greater lignin content, yield the maximum biochar yields at 500 °C equaled to lesser and higher temperatures of pyrolysis (Fushimi et al. 2003). Mostly pyrolysis typically generates a compact, organized, carbonaceous material that shows high surface area as compared to feed stock (Bird et al. 2008), has less hydrogen and oxygen content (Abdullah and Wu, 2009) has more nutrients (Agblevor et al. 2010). Both mass yields obtained and the amounts of aromaticity are feed stocks functions and conditions of pyrolysis. Temperature, degree of heating, flow rate of sweep-gas rate and raw material element mass are all features that affect the mass yield of biochar

2.2 Production methods

2.2.1 Slow Pyrolysis

Slow pyrolysis can be categorized as a rather low-tech and robust technology which has been optimized for biochar production. Historically, slow pyrolysis of woody biomass in traditional kilns has been the most widespread application for charcoal production (Antal and Gronli, 2003). At low temperatures, between 20 °C and 150 °C, timber dehydrates, ensuing in a loss of mass and hemicelluloses modifies (Eateves and Pereira, 2009) by deacetylation and depolymerisation, releasing acetic acid that acts as a catalyst in the depolymerisation of the polysaccharides (Nuopponen et al. 2004). Hemicelluloses further dehydrate occasioning in a lessening in the amount of hydroxyl groups (Zhang et al., 2010). Above 250 °C, lignin carbonization happens, which results in rise in the carbon content creating char, while the concentrations of oxygen and hydrogen decline (Lehmann, 2007). This results in structural fluctuations and compression reactions to method (Windeisen and Wegener, 2008) emitting CO₂ and VOCs.

Slow pyrolysis has numerous benefits comparative to other thermochemical change skills; the units incline to be small and cheap, they receive various bases of feedstock, and the feedstock is not necessarily to be superbly crushed. Slow pyrolysis is, however, hard to balance because heat transference into rough biomass is quite sluggish, so the feedstock has a moderately long dwelling time in the reaction chamber (Amonette and Joseph, 2009). Current process of slow pyrolysis mostly occurs in nonstop devices, e.g. drum pyrolysers, rotary kilns, or screw pyrolysers (Brown, 2009). These plants, which, besides charcoal, collect bio-oil and syngas, are highly energy efficient compared to traditional kilns. Slow pyrolysis yields more biochar and reduced quantities of functioning energy products than other thermochemical transformation tools. As such slow

pyrolysis seem to be unsurpassed suitable for providing minor sums of heat and/or power to attached services in distant places, particularly in areas with a high plea for biochar.

2.2 Fast Pyrolysis

Fast pyrolysis plants use high-tech continuous processes designed to give a large fraction of liquid product (Yanik, et al. 2007). In fast pyrolysis, biomass is quickly (<1 s) heated to 400-700°C in the lack of oxygen. To attain such swift heating proportions, the element mass of the feedstock is mostly decreased to < 2 mm (Cummer and Brown, 2002), which needs major quantities of energy. The key energy produce, bio-oil, is a murky brown fluid attained by reduction of the pyrolysis gas. Fast Pyrolysis produces 60-70 percentage of the original biomass as bio-oil and 15-25 mass percent as biochar (Mohan et al. 2006). Higher temperature induces the polymerization of the altered biochemical products to produce greater particles that are fragrant and aliphatic in nature (Verheijen et al. 2009); moreover, pore volume and surface area increase at higher temperatures (James et al. 2005; Zhang et al. 2010).

Though, the material used regulates the top temperatures at which the micro pores are unlocked up within the biochar. Total energy retrieval by fast pyrolysis depends chiefly on the wetness of the biomass used as raw material. If feedstock used is dry then stated energy recoveries in the bio-oil fraction are ~50 percent, and total energy recoveries (in the bio-oil and biochar) are ~75 percent relative to the energy content of the original biomass (Mullen et al. 2010). Current readings (Jones et al. 2009; Sohi et al. 2010) confirmed that at least 40 mass percent of fast pyrolysis oil can be changed into green gasoline and green diesel at a cost of 0.53 \$ per L.. Fast pyrolysis, grounded on fluidized and mingling bed reactors, are normally accessible but requisite to function at suggestively greater scales than slow pyrolysis to be economically feasible. The financial practicality of fast pyrolysis depends critically on the marketplace for bio-oil; trade of the biochar co-product will offer a quite small minor source of income. The development of a fast pyrolysis business is presently narrow by the lack of factories capable to change bio-oils into transport fuels and other high value products (Jones et al. 2009).

Along with traditional pyrolysis methods to produce char, alternate ways have been discovered. These comprise hydrothermal carbonization (Steinbeiss et al. 2009; Fuertes et al. 2010), pressed pyrolysis (Mahinpey et al. 2009) and heat pyrolysis (Lei et al. 2009). These later procedures have potential as ways to resources with properties outside the choice of usual pyrolysis products and higher energy efficiency.

2.3 Biochar properties

Biochar is a fresh formed systematic term, well-defined as a carbon-riched product by thermal breakdown of biomass (e.g., greensward, timber, dairy compost, broiler litter, and crop remains) in the fractional or complete lack of oxygen (Cao and Harris, 2010) (Lehmann and Joseph, 2009). It has received consideration in waste discarding and soil remediation in current ages.

The International Biochar Initiative (IBI) describes biochar as a hard material attained by the thermochemical renovation of biomass in an oxygen depleted situation (IBI, 2012). Mostly carbon molecules in biochar are systematized in aromatic rings of six carbon atoms connected with each other by double bonds lacking oxygen or hydrogen. Though, engagements of atoms of carbon in biochar are asymmetrical, compound and inconstant because of special effects of the inorganic part of feedstock (Schmidt and Noack, 2000). Many supplies are used as raw material comprising slurry, husk of rice, herb constituents, wood, municipal waste and composts. Wood mainly comprises of cellulose, hemicellulose and lignin. But the wood species differ in their structures as softwood differs from hard wood (Windeisen and Wegener, 2008). Transformation of biomass can be carried out in a reactor by carbonization or gasification at different temperatures depending upon the use of end product (Verheijen et al. 2009).

In addition, the large C constituent, the essential arrangement of biochar contain of H and O, as well as many minerals (e.g. N, P, S) dependent on the feedstock (Lehmann and Joseph, 2009). Inorganic components are mostly instituted as heteroatoms combined into the aromatic rings, and these are assumed to take part to the highly diverse external reactivity of biochar (Verheijen et al. 2010). Biochar might comprise many useful surface groups, like hydroxyl-OH, keton-OR, ester-(C = O), aldehyde-(C = O) H, amino-NH₂, nitro-NO₂ and carboxyl-(C = O) OH groups (Amonette and Joseph, 2009). Extremely heterogenic surface thus displays hydrophilic and hydrophobic as well as acidic and basic properties, and contributes to biochar's capacity to react with a wide range of inorganic and organic compounds in the soil solution (Atkinson et al. 2010). Freshly produced biochars, though, are usually hydrophobic in nature, due to predominantly non-polar surface characteristics (e.g. carbohydrate or aromatic characteristics) (Lehmann et al. 2009).

Most N and S compounds, however, volatilize above 200°C and 375°C, respectively, while K and P volatilize between 700°C and 800°C (DeLuca et al. 2009). Most biochars are produced in the temperature range 450–550 C and, as a result, tend to be relatively depleted in N and S.

However, those produced from N-rich feedstocks (e.g., biosolid biochar) at the lower end of the temperature range (e.g., 450°C) may retain up to 50% of its original N content and its entire S and, as a result, are comparably richer in these elements than wood-based biochars produced at higher temperature (Bridle and Pritchard, 2004). Most wood- and nut-based biochars have extremely high C/P and C/N ratios. Conversely, manure-, crop-, and food-waste biochars have much lower ratios with manure-derived biochars being the most nutrient-rich relative to C, especially in P relative to N. Nutrient-rich and ash-rich biochars lack the stability that is associated with C-rich and highly aromatic and condensed wood-derived biochars (Singh et al. 2010b). Production temperature can also alter the extractability of certain nutrients and the physical and chemical properties of biochars: high-temperature biochars (800°C) tend to have a higher pH, electrical conductivity (EC), and extractable NO₃, while low-temperature biochars (350°C) have greater amounts of extractable P, NH⁴⁺, and phenols (DeLuca et al. 2009).

Sizes of pores in biochar are stated to vary from < 2 nm to > 50 nm, with an upturn in the small width pore portion as temperature of pyrolysis rises (Downie et al. 2009). Effective value of biochar is great. It could be utilized for filtration of pyrolysis drain vapors (Lehmann, 2007) help as primary material to make nitrogen manures (Marris, 2006), we can generate activated carbon by treating biochar with steam (McHenry, 2008) and as a farmhouse compost as well as it is good method to recover plantation efficiency. Biochar applied in soil is supposed to stock carbon for centuries theoretically leading to a substantial decrease in greenhouse gases in the atmosphere (Lehmann, 2007). The substantial characters of biochar vary from those of unexplored biological material in soil (Schmidt and Noack, 2000), and there is variation in them with passage of time because of weathering courses, interfaces with soil inorganic and organic substance and deterioration by microbes in soil (Nguyen et al. 2010).

Conformation of biochar can be roughly separated into rather intractable C, reactive or percolate able C and residue. Main biochemical variance among biochar and other biological material is greater amount of aromatic C and, specially, the existence of bonded aromatic C arrangements, in comparison with other aromatic constructions of soil carbon-based matter like lignin (Schmidt and Noack, 2000). These bonded structures of biochars have variable formulas, comprising shapeless C, which is central at lesser pyrolysis temperatures, and turbostratic C, formed at greater temperatures (Keiluweit et al. 2010; Nguyen et al. 2010). It is evident that the nature of these C assemblies is main motive for the high constancy of biochars (Nguyen et al.

2010). Biochar structure is greatly diverse, comprising together constant and labile constituents (Sohi et al. 2009). Volatile matter (0-40%), carbon (50-90%), mineral matter (ash) 0.5-5% and humidity (1-15%) are normally considered as its main elements (Antal and Gronli, 2003).

Carrier materials used include sawdust, wheat bran and calcium alginate and biochar (Rahman et al. 2006). Ideally, such a matrix is biodegradable, available in large supplies, can be produced with low cost, and have appropriate physical properties to allow sufficient infusion with specific microorganisms to remediate pollution. Currently, biochar intentionally made by biomass pyrolysis has received increasing considerable attention as a possible potential low-cost adsorbent tool to sequester contaminants and control pollutant migration (Zimmerman, 2010). Biochar can protect prevent organic pollutants as biosorption and bioaccumulation, subsequently reduce the ecological risk by adsorption (Yang et al. 2012). Study conducted by Jia et al. (2014) showed that adding biochar at 1% in sediment with low organic carbon content (0.12%), the free dissolved concentrations of PAHs were reduced by 47.5-78.0%. The variations caused by addition of biochar in the soil result in changes in quality of soil (Paz-Ferreiro and Fu, 2014) as well as increase agronomic incomes (Jeffery et al. 2011; Liu et al. 2013). The extensive choice of procedure factors indicates the development of biochar products that differ significantly in their essential and ash conformation, compactness, absorbency, pore size delivery, surface area, surface biochemical features, water and ion adsorption and discharge, pH and consistency of biochars' physical arrangement (Downie et al. 2009; Krull et al. 2009; Chan and Xu, 2009). The elemental composition of biochar generally include carbon, nitrogen, hydrogen, and some lower nutrient element, such as K, Ca, Na, and Mg (Zhang et al. 2015). Commonly, the carbon content increased with increasing pyrolysis temperature from 300 to 800 °C, while the contents of nitrogen and hydrogen decreased. Biochar has a high specific surface area and a number of polar or nonpolar substances, which has a strong affinity to inorganic ions such as heavy metal ions, phosphate, and nitrate (Schmidt et al. 2015; Kammann et al. 2015).

2.4 Biochar characteristics and factors affecting its functional properties

Main characters of biochar, like surface area, pH, ash, volatiles, solidity and pore-volume, water retention capability are important that effect sensitive functions of biochar (Okimori et al. 2003). Significant factor that leads the status of these physicochemical properties is feed stock used to produce biochar. Form and bulk of the feedstock and product of pyrolysis affect the quality and possible uses of biochar. Woody feedstocks produce biochars that are rougher and mostly

xylemic in nature, while biochars from residues of crop rye or maize and composts proposes a better and more delicate structure (Sohi et al. 2009).

The degree of aromatic structures formation in bio char is affected by temperature (Brewer et al. 2009) and time at temperature (Yip et al. 2011). Rise in pyrolysis temperature leads to enhance surface area of biochar that facilitates sorption of chemicals like heavy metals and pesticides. Biochar quality in certain circumstances is determined by aromatic structure. Larger aromatic regions lead to greater cation exchange capacity in soil (Joseph et al. 2009). Rise in char aromaticity indicates to more resistance in soil alongside prolonged reposition potential. Pyrolysis temperature is the most significant parameter that leads to an assessable analogous to activated carbon (Ogawa et al. 2006). As temperatures during pyrolysis rises, volatile complexes present in the feedstock medium are lost, ash and surface area proliferates but functional groups at surface which offer exchange sites reduce (Guo and Rockstraw, 2007). Lignocellulose breakdown initiates at about 120°C, hemicelluloses are vanished at 200-260°C, cellulose between 240 and 350°C and lignin is degraded at 280 to 350°C. High temperature of biochar shows high surface area and permeability, both of that are used in adsorption-based remediation technologies.

To increase the adsorption ability of biochar, a mechanical condensation stimulation of biochar speed up its positive effects on nutrient preservation and acceptance by plants relative to non-activated biochar (Borchard et al. 2012). Steam activation revealed practically twice the positive effects of biochars in all cases, thus being a remarkable option for future biochar applications. Activation procedure enhances the permeable structure and sorption characters of biochar. Another treatment method that affects the function of biochar is magnetization, which is also a valuable technique to increase biochar property (Chen et al. 2011). Magnetic biochars have greater sorption competency in comparison to non-magnetic biochars. So, magnetization is alternative while refining sorption ability of biochar. New treatment methods such as oxidization of biochar by many oxidants like K_2MnO_4 , H_2O_2 (Chao et al. 2010), air (Klasson et al. 2009) and O_3 could also progress bio-char characters and improve adsorption result. Biochar oxidized by H_2SO_4/HNO_3 has more carboxyl group and demonstrated higher immobilization to Pb, Cu and Zn (Sanchez and Utrilla, 2002).

The composition of biochar components like ash, moisture contents and fixed carbon controls the biochemical and physical actions and function of biochar entirely (Brown, 2009), that

in chance regulates biochar aptness to apply for specific site, as well as transportation and providence in the environment (Downie, 2009).

3. Biochar application in heavy metals contaminated soils

When biochar is added to soil, it shows oxidation by forming efficient groups, and provides locates which hold nutrients and other organic compounds (Cheng et al. 2008). Process of oxidation enhances O and H and reduces C concentrations and the forms functional groups that contain O as well as decrease negative charges at surface (Baldock et al. 2002). This potency is increased by temperature of the biochar production (Nuopponen et al. 2004) and by using chemical oxidants (Kawamoto et al. 2005). Particles of biochar present in soil are aged then further oxidation conduce the development of negative charges so increases the CEC (Hammes et al. 2009). Particles of biochar that are oxidized are bound to minerals present in soil by linking with soil and silt-sized minerals that reduce the potential of its decay. When biochar particles bound to soil minerals, they increase the capacity of the soil-biochar compound to sorb organic composites existing in soil. Biochar also binds directly with carbon-based substances of soil by sorption (Browdowski et al. 2005).

3.1 Effect on Soil properties

Over the past decade, research has shown that biochar is more stable than any other additive in the soil profile, which increases nutrient availability beyond a fertilizer effect (Lehmann, 2009) due to its high surface area. The capacity and stability of biochar to retain nutrients is more than other organic material in the soil environment, to improve soil health and quality. Physical and chemical properties of the biochar including greater nutrient retention (Lehmann et al. 2003), high charge density (Liang et al. 2006), and particulate nature in combination with a unique structure (Baldock and Smernik, 2002) provides more resistance to microbial decay when compared with other soil organic matter content (Cheng et al. 2008). Biochar is preferred over other sorbents like compost, farm yard manure and poultry manure etc. because of its higher retention capacity in soil over decades (Westrell et al. 2004).

Several readings show that biochar is a valuable reserve to recover the physicochemical properties of soil, efficiently sustain SOM levels, it increases manure use efficiency and enhance production of crop, chiefly for long-term cultured soils in subtropical and tropical areas (Deenik et al. 2011; Van Zwieten et al. 2010). The assimilation of biochar into soil adjusts soil physical

properties, such as structure, texture, porosity, bulk density, and particle size distribution. This may in turn have consequences for important soil functions e.g. soil aeration, water holding capacity, and plant growth (Atkinson et al. 2010).

Biochars density is much lesser than inorganic soil. Therefore, addition of biochar to soil increases the soil volume and decreases the bulk density of the soil. Assimilation of bigger biochar elements (e.g. > 0.5 mm) results in amplified ventilation of the soil and reduces anoxic microsites that effect several soil courses such as decay degrees of organic matter, nitrification, denitrification dynamics, and emissions of GHG's. Compaction of the soil after biochar application is another possibility. If fine biochar are incorporated in soil, particles may fill existing soil pores and thus potentially compact the soil and increase soil bulk density.

It is also found that biochar improves the water holding capacity in sandy soils and sand mixes when it is applied at reasonably great rates (25-45 vol %) (Brockhoff, et al. 2010), but it also decreases moistness in clayish soils (Verheijen, et al. 2010). It is also stated that hydrophobic biochars cause better flow, and reduce penetration of water thereby lessening the water holding capacity (WHC) of clay soils (Major et al. 2010a). Positive impact of biochars on soil water holding capacity is connected to great micropore volume, which may hold water (Verheijen et al. 2010). Leakage of nutrients from agronomic soil drains productiveness of soil enhances the requirement for synthetic or organic fertilizer input that results in eutrophication of ground- and surface waters (Laird et al. 2010). Biochar use reduces nutrient discharge from soil (Ding et al. 2010; Laird et al. 2010; Novak et al. 2009). The nutrient retention ability of biochar is mostly qualified to biochars greater surface area providing adsorption sites for inorganic nutrients. Furthermore, biochar capability to enhance the water holding capacity of soils also improves nutrient retention time in the topsoil. The attachment to biochar of biological matter or minerals with sorbed nutrients (aggregation) further increases the nutrient retaining (Major et al. 2010a).

Biochar also serves as a liming agent resultant in better pH and nutrient obtainability for different soil types (Lehmann and Rondon, 2006). The carbonate application of biochar enables liming in soils and raises soil pH of neutral or acidic soil (Van Zweiten et al. 2007). Biochar is porous solid, carbon rich (Wang et al. 2010; Liu et al. 2011; Xu et al. 2013) and highly recalcitrant (Steiner et al. 2007) product of process of pyrolysis of organic materials. A wide range of materials can be used as feedstocks i.e. Manures, sludge, crop and plant residues, paper and pulp waste materials (Glaser et al. 2002). Typically, biochar has high pH and CEC value and it can enhance

the soil productivity (Kookana et al. 2011; Jeffery et al. 2011). It can enhance water retention (Glaser et al. 2002), nutrients retention thus prevents the leaching losses, increases CEC (Glaser et al, 2002; Lehman et al. 2003; Major et al. 2010), affects the pH (Hossain et al. 2012; Uchimiya et al. 2010) and soil respiration (Smith *et al.*, 2010). Therefore, it affects the porosity and consistency by changes in density, pore size, particle size distribution and bulk surface area (Downie et al. 2009). Biochar significantly improve soil properties. Many of them are interrelated and have potential to act synergistically.

The cation exchange capacity (CEC) of soil is defined as a degree for how good cations e.g. ammonium, potassium, calcium etc. are destined in the soil. The cation preservation of soils is found to rise after applying biochar, often due to biochars greater surface charge density that permit the maintenance of ions (Van Zwieten, et al. 2010). Cations are bound by ion- and covalent bindings to negatively charged sites on the reactive surface of biochar (and clay and organic matter). On the contrary anions (e.g. N-oxides and phosphates) are bound very weakly in soils under neutral to alkaline pH conditions, mainly due to the negative surface charge of clay.

Biochar capacity for abatement of soil/residue contaminants by sorption and sequestration is well documented progressively (Yu et al. 2010; Chen and Yuan, 2011) with great micro porosity and surface area and diverse surface physico -chemical properties (Yu et al. 2006) as main factors.

Aggregate formation and stabilization promotes long term carbon sequestration and soil structural stability and are affected by various factors, including clay content, and types and amount of soil organic matter (SOM) (Six et al. 2004). Organic materials are the main agents of formation and stabilization of macro aggregates, including persistent cementing agents, such as humic matter, and transient and temporary bonding agents, such as fungal hyphae and microbial extracellular polysaccharides (Six et al. 2004). Biochar is organic matter, but the very slow breakdown in soil marks it distinct as compared to other soil organic carbon groups and it gives most of similar soil facilities as SOM, like soil maintenance by accumulation, and holding of nutrients and water.

Biochar also supplies vital macro- and micronutrients helpful for the plant and soil microscopic community. Because of basic characters of the inorganic concentration in biochar, biochar generally has a neutral to alkaline pH value. Additionally, labile organic biochar portions are also advantageous for the microbial community (Steiner et al. 2008a).

Despite the importance of soil microorganisms to soil fertility and nutrient cycling, the impact of biochar on soil microbial communities is poorly understood. Application of biochar reduces nitrous oxide and methane emissions from acid savannah soils (Rondon et al. 2005), suggesting that the application of biochar may increase soil aeration or otherwise affect soil microbial communities. In addition to affecting measurable biogeochemical processes, biochar-enriched soils are associated with increased bacterial (Pietikäinen et al. 2000) and fungal (Warnock et al. 2007) growth rates, and greater overall cell biomass (Zackrisson et al. 1996). Warnock et al. (2007) proposed that biochar encourages the growth of microorganisms through increased nutrient availability (N, P and metal ions), induction of „mycorrhizal helper bacteria with beneficial metabolite production, and direct physical protection of bacteria, from grazing predation, within biochar pores. About 16 of 20 microbial isolates from biochar-amended soils corresponded to plant growth promoting and/or biocontrol agents (Graber et al. 2010). The plant growth promoting organism *Trichoderma* was only isolated from the rhizosphere of pepper plants when biochar had been applied (Graber et al. 2010). The earthworm *Geopharous* may feed on microbes and microbial metabolites that are more abundant on biochar surfaces (Lavelle, 1988). The tropical endogenic earthworm species *Pontscolex corethrurus* was found to prefer biochar amended soil, and ingests it for purposes other than obtaining nutrients (Topoliantz and Ponge, 2003, 2005). Biochar may be used as an inoculant carrier, substituting for the increasingly expensive and GHG releasing peat (Tilak and Rao, 1978, Ogawa 1989, Beck 1991).

Surfaces of biochar help as promising places for microbes because of greater concentrations of adsorbed nutrients. Their specific pore size characteristics may also exclude predators such as protozoa and nematodes and thus favoring the colonization by bacteria and fungi (Thies and Rilling, 2009). It is not clear whether microbes actively infiltrate biochar particles or colonize the outer surfaces containing adsorbed nutrients and fresh organic matter (Hammes and Schmidt, 2009). Enhanced colonization but decreased respiratory activity of microbes has been observed in biochar-amended soils and it is also found that soil respiration decreased with increasing application rate of biochar (Weyers et al. 2010). Increased mycorrhizal colonization has been observed when soils were amended with some biochars (Solaiman et al. 2010), apparently indirectly by increasing P solubility in soils (Solaiman et al. 2010). In temperate ecosystems with wildfire-produced charcoal, N mineralization and nitrification are enhanced (Berglund et al. 2004;

Gundale and DeLuca, 2007) creates encouraging microenvironments that increase colonization by microorganisms (Warnock et al. 2007).

Addition of biochar to topsoil improves crop yield (Asai et al. 2009) particularly in soils with reduced fruitfulness that is extremely striking and assumed to contribute to the fast upsurge in worldwide population and shrinkage of productive land area. The improved growth of plants is considered to be linked with better features of soil by adding biochar amendment. Biochar also contributes to increase resistance of crops to disease and more crop output (Elad et al. 2010). So, biochar serves as an infection control agent in agriculture. Developments of plant reactions to disease are one of the important profits gained by application biochar to soil (Elad et al. 2011).

Moreover, biochar could increase soil fertility by reducing the N₂O and NO emissions. Relatively, the low-temperature biochars could be more efficient for reducing N₂O emission. Fourthly, biochar could improve soil biological properties, including microbial abundance, structure, and activity. Biochar could improve microbial community by increasing nutrient availability, providing suitable shelter, and ameliorating living condition. The improved microbial community could facilitate nutrients cycling, which could decrease the emissions of gaseous nutrients and increase the retention of nutrients.

On the one hand, the properties of soils, containing physical, chemical, and biological properties, could be improved after biochar treatment. Moreover, the improvement of soils properties is highly related to the specific physicochemical properties of biochar, such as high surface area, amount of functional groups, and the content of liming. For example, soil's cation exchange capacity may increase with the increase of carboxylic groups and surface area. The well-developed pore structure may not only enhance the capacity of water retention but also provide a shelter for soil's microorganisms, thus nutrient retention and cycling could be improved. The content of liming contained in biochar may increase soil's pH values. On the other hand, biochar could increase plant nutrient availability in soils by releasing nutrients, retaining nutrients, reducing nutrients leaching, and mitigating gaseous N losses. Therefore, biochar has great potential in the improvement of soil fertility (Ding et al. 2016).

Crop yield increase by application of biochar has been reported by various researchers (Marjenah, 1994; Yamato et al. 2006). Recently there has been great emphasis by scientific community on raising awareness about improvement of plant responses to environmental stresses

(Graber et al., 2010). Therefore, biochar has the potential to uplift agricultural e.g. It has been reported that biochar tends to increase the above ground biomass ranging from 10% (Jeffery et al. 2011) to 30% (Biederman and Harpole, 2013). (Liu et al. 2013) reviewed and demonstrated biochar application result in an overall mean 11% increase in crop productivity.

3.2 Effect of biochar on heavy metal mobility

Industrial development and mechanical progresses have headed to rise in the usage of heavy metals and heavy metal pollution. In current centuries, progressively more soils are being polluted with organic and inorganic contaminants worldwide owing to excess releases from industries, mining actions, waste (i.e., biosolids and manures) application, wastewater irrigation, and insufficient administration of pesticides and substances in farming production (Mench et al. 2010). Degraded soil is mostly considered by a deficiency of upper soil so, a vulnerability to development through by compost adding. Where the soil is polluted with metals the supplementation also results in immobilization (Gadepalle et al. 2007) although on a brief basis (Van Herwijnen et al. 2007) this can be prolonged by the applying biochar (Hartley et al. 2009). Alternate opinion is that, after carbon-rich additions, the metals are evacuated as organic complexes (Cao et al. 2009).

Contaminants in lands are not only damaging to ecologies and agronomic production but also a severe danger to human welfare. Heavy metals are not biodegradable and gather in the environment and continue for a long time in polluted soils. It is costly and time consuming to eliminate heavy metals from polluted soils (Cui and Zhang, 2012). However certain soils can have a high contextual level of heavy metals due to volcanic activity or weathering of parent materials, in other soils human actions, comprising mining, smelting, fertilizers, use of pesticides and sludge are accountable for these high levels of heavy metals. Soil heavy metal pollution has a malicious influence on soil microscopic properties (Yang et al. 2012) and on the taxonomic and practical variety of soils (Vacca et al. 2012). Heavy metal pollution in soil poses a threat to the environment and to human health (Roy and McDonald, 2014) due to bio magnification. Some of these components are vital for living organisms but some others are non-essential.

Biochar applied to soil decreases the mobility of heavy metals in polluted soils, reducing threat of metal uptake by plants. Bamboo derived biochar can adsorb Hg, Ni, Cu, and Cr from both water and soils, and Cd in contaminated soils (Cheng et al. 2006). Characters of biochar are a task of feedstock and pyrolytic situations, so not only one kind of biochar could be completely used to

amend soils polluted with many kinds of heavy metals. The effect of biochar on mobility of heavy metal differs with the forms of biochar and heavy metals kinds (Table 1). The amount of extractible As and Zn in soil enhanced when biochar was applied, while the amount of extractible Pb lessened, Cu did not show any change, and Cd showed an unpredictable drift (Namgay et al. 2010). Use of biochar can also decrease the leaking of metals by its redox effect reactions of metals. The use of biochar resulting from chicken compost to chromate (Cr VI) polluted soils improved the decrease of moveable Cr(VI) to less mobile Cr(III), thus lessening the discharge of Cr (Choppala et al. 2012).

Converting straw to biochar for use as a soil conditioner has become a hot topic in agriculture, environmental science, and other fields, due to its advantages in soil carbon sequestration and CH₄ emission reduction (Zhao et al. 2014), and its sorptive capacity for soil pollutants (Lu et al. 2014 Kim et al. 2015 and Puga et al. 2015). Biochar is a stable form of organic matter (OM) that can sorb and immobilize metals, potentially limiting their long-term mobility and bioavailability in soil. Biochar has a high density of negatively charged functional groups on its surface that sorb cations such as Cd (Uras et al. 2012; Wu et al. 2012). Namgay et al. (2010) suggested lower concentrations of heavy metals e.g., Cd in maize shoots with biochar application. Sizmur et al. (2011) found that the treatments containing biochar and earthworms did not result in higher heavy metal mobility or plant availability. Application of environmental friendly options including biochar amendments can limit the hazardous effects posed by the Cd levels in the soil.

3.3 Effect of biochar on the bioavailability of heavy metals

Heavy metals bioavailability regulates the harmfulness in the soil and possible threat by incoming human nutrition chain. The bioavailability of contaminants directs their ecotoxicology and breakdown in polluted soils. Potential of addition of biochar to amend the heavy metal toxicity in the mine tailings was assessed by Fellet et al. (2011). Crop remains at four rates (0 %, 1 %, 5 %, and 10 % biochar in the mine tailings) was applied. The cation exchange capacity, pH and the water-holding capacity improved as the biochar amounts enhanced and the bioavailability of Cd, Pb, and Zn of the mine tailings reduced, with Cd having the highest decrease. Effects of biochar derivative from manure slurry on heavy metals solubility and bioavailability in a Mediterranean agronomic soil was studied and related with those of sewage sludge, which was not burnt. The biochar actions condensed plant obtainability of Ni, Zn, Cd, and Pb when associated to sewage sludge usages (Mendez et al. 2012). Various readings presented that biochar can decrease heavy

metal movement and its bioavailability (Table 2), but mostly these investigations were directed under measured research laboratory and green-house trials and in small design trials. Usefulness of biochar will be when field trials at large scale will be conducted to remediate contaminated soils.

3.4 Interaction mechanisms between biochar and heavy metals

Biochar features serve purpose of numerous reasons, comprising the kind of feedstock, the element mass of the feed-stock and temperature and conditions of pyrolysis. The wide ranges of physical characteristics of biochar make some specific materials more appropriate than others to amend different heavy metals. So, while choosing a biochar to remediate heavy metals, scientists are conscious not only of soil type and characteristics but also on biochar properties. Moreover, they also consider key biochar properties like surface area, pH, ash and carbon matters can be affected by post-treatments and thus boost biochars' ability to immobilize heavy metals (Lima et al., 2014). Biochars act on the bioavailable portion of soil heavy metals and that they decrease their leach ability. Alkalinity of biochar could also be moderately liable for lesser amount of accessible heavy metals originated soils that are amended with biochar. Higher pH values of soil also result in heavy metal precipitation in soils. pH value of biochar is increased with pyrolysis temperature (Wu et al., 2012). Biochar also reduces the mobility of heavy metals by changing the redox state of those (Choppala et al., 2012).

The variable physical and chemical properties of biochar may mobilize and immobilize a variety of soil contaminants such as heavy metals and organic pollutants by direct and indirect means including sorption, ion exchange and precipitation mechanisms, pH change, and manipulation of redox balance. Biochar also influences the rate of degradation of organic pollutants by altering microbial activities in many ways (Kumar *et al.*, 2016). One of the main features of biochar is having large surface areas; that involves a high ability for complex heavy metals on their surface.

Several cases using skimming electron microscopy (Beesley and Marmiroli, 2011; Lu et al. 2012). This sorption is because of complex formation of the heavy metals with different functional groups that exist in the biochar, owing to the interchange of heavy metals with cations related with biochar, like Mg^{+2} and Ca^{+2} (Lu et al. 2012), Na^+ , K^+ , and S (Uchimiya et al., 2011c), or due to physical adsorption (Lu et al., 2012). Removal of mechanisms of heavy metals with

biochar alteration is recognized to electrostatic relations, precipitation and other feedbacks as shown by recent studies (Dong et al. 2011). When biochar is added to soil, then negative charges on soil surface increase due to decreased zeta potential and more CEC (Peng et al. 2011). So, the electrostatic magnetism among heavy metals with positive charge and soil is becomes higher. With relative to precipitation, the enhanced soil pH rising from biochar improvement leads to reduced movement of heavy metal. Numerous phosphate, oxidates, or carbonates are made in changed situations. Certain other more composite mechanisms also play a major role during biochar and heavy metal exchanges. As surface of biochar has many functional groups (alcohol, hydroxyl and carboxylic group etc.) so it is easy to formulate new complexes between heavy metals and these groups. Likewise, functional groups of oxygen are well-known to stabilize heavy metals in the biochar surface, mainly (Uchimiya et al. 2011c) for weaker acids like Pb^{+2} and Cu^{+2} . Several new composites existing in the residue, like phosphates, carbonates or sulphates (Park et al. 2013) support to stable heavy metals by precipitation of these complexes with the contaminants. of enzymatic activities, increased nutrient uptake and other mechanisms (Dobereiner and Pedrosa, 1987; Dobbelaere et al. 2003). Biochar can be manipulated to contain critical plant nutrients (Radlein et al. 1997) even unmodified biochars improve soil fertility because their high surface area retains water and nutrients (Marris, 2006). Discoveries of long abandoned biochar treated sites in the Amazon Basin show that these effects can last for 1000s of years (Liang et al. 2008).

Table: 1 Influence of biochar application impact on heavy metal movement and remediation in soil

Feedstock	Production temperature	Pollutant	Effects observed	Reference
Maize	750°C	zinc and cadmium	Reduced plant uptake of zinc and cadmium and increased the metal concentration in leachates	Wagner and Kaupenjohann, (2014)
mixed wood	450°C	copper, cadmium and nickel	Effective metal immobilization in biochar-amended soils	Rees et al. 2014
Coniferos and hardwood chips	450°C	Pb, Cu, Cd, Zn and Ni	Contaminated soil has shown a significant reduction of extractability of Pb, Cu, Cd, Zn and Ni	Rees et al. 2014
Paper mill sludge	200–700°C	Cr, Cu, Ni, Zn, Pb, and Cd	Significant reduction in the mobility of the heavy metals	Devi and Saroha, 2014
Poultry litter and eucalypts.	400°C (poultry litter biochar) or 600°C (Eucalyptus biochar)	Cd	Reduce rice Cd uptake through a reduction in Cd mobility	Ku et al. 2014
wheat straw	350 and 550 °C	Cd	Effectively immobilized Cd and greatly reduced rice Cd uptake in long-term contaminated rice paddies	Biana et al. 2013
Miscanthus straw	600°C	Cd, Zn and Pb	Cd, Zn and Pb were 2.5, 5.4 and 3.8 times lower	Houben et al. 2013
Wood	200 °C and 400 °C	Cd, Zn	Decrease in Zn and Cd percolating loss by >90 %	Debela et al. 2012

Hardwood	450 °C	As, Cd, Cu, Zn	Lessening of Cd in soil aperture water by 10-folds; Zn amounts decreased 300- and 45-folds, separately, in column leakage experiments	Beesley et al. 2010); Beesley and Marmiroli, (2011)
Bamboo	Not available	Cd	Mutual influence of electrokinetics, elimination of extractable Cd by 79.6 % within 12 days	Ma et al. (2007)
Hardwood	450 °C	As, Cd, Cu, Pb, Zn	Biochar external covering improved As and Cu movement in the soil profile; slight effect on Cd and Pb	Beesley and Dickinson, (2011)

Table 2: Effect of biochar on the bioavailability of heavy metals (Adapted and modified by Zhang *et al.*, 2013)

Feedstock	Production temperature	Contaminants	Effect observed	Reference
Bamboo and rice straw	750 °C, 500 °C	Cd, Cu, Pb and Zn	Reduced the uptake of Cd, Cu, Pb and Zn by <i>S. plumbizincicola</i> , Rice straw biochar was more effective to reduce Cu and Pb while Bamboo biochar was effective to reduce Cd	Lua et al. 2014
Chicken manure	550 °C	Cr	Increased soil Cr(VI), decrease to Cr(III)	Choppala et al. 2012
Rice straw	Not clear	Cu, Pb, Cd	Noteworthy decrease in amounts of free Cu, Pb, and Cd in polluted soils; documentation of efficient groups on biochar with great adsorption attraction to Cu	Jiang et al. 2012
Quail litter	500 °C	Cd	Decrease of the concentration of Cd in physic nut; more decline with the advanced application proportions	Suppadit et al. 2012
Oak wood	400 °C	Pb	Bioavailability decrease by 75.8 %; bio accessibility reduction by 12.5 %	Ahmad et al., 2012
Orchard prune residue	500 °C	Cd, Cr, Cu, Ni, Pb, Zn	Major reduction of the bioavailable Cd, Pb, and Zn, with Cd showing the greatest reduction; an increase in the pH, CEC, and water-holding capacity	Fellet et al. 2011
Chicken manure and green waste	550 °C	Cd, Cu, Pb	Significant reduction of Cd, Cu, and Pb accumulation by Indian mustard	Park et al. 2011

Eucalyptus As,	550 °C	Cd, Cu, Pb, Zn	Decrease in As, Cd, Cu, and Pb in maize shoots	Namgay et al. 2010
Hardwood-derived biochar	400 °C	As	Significant reduction of As in the foliage of <i>Miscanthus</i>	Hartley et al. 2009
Cotton stalks	450 °C	Cd	Reduction of the bioavailability of Cd in soil by adsorption or co-precipitation	Zhou et al. 2008

Thus, biochar amended soils reduce N fertilizer application and so can lessen groundwater water contamination and lead to reduced emissions of the very potent greenhouse gas (GHG) nitrous oxide (N₂O). Biochar enriched soils are associated with increased microbial dynamics due to sorption and inactivation of growth inhibiting substances (Lehmann et al. 2011), increased nutrient availability (N, P and metal ions) and direct physical protection from grazing predation within biochar pores (Warnock et al. 2007).

Heavy metals at high concentration can cause toxicity of microbial cells which limits the remediation process compared to indigenous microbes. Application of suitable carrier can provide a refuge for the microbes. The used carrier should be environmentally friendly because it is not necessary to recover these immobilized cells after adding in contaminated site (Cassidy et al. 1996; Cunningham et al. 2004; Mohammadi et al. 2009). These carriers intended to provide a protective niche for the selected microbes against the harsh environment and competitive indigenous microorganisms. Fresh plant residues were used in the past as conventional carriers owing their high affinity for microbes and enzymes (Dzul-pue et al. 2005). The enhanced degradation of the pollutants was observed using biochar as carrier compared to free microorganism and it was noted that degradation rate was significantly higher compared to free cells inoculations (Su et al. 2006). This effect is summarized in Table 2. Fresh plant materials were considered as biosorbent materials for organic and inorganic contaminants (Can et al. 2011b), but their adsorption capabilities were comparable to soil organic matter. Therefore, a novel should be investigated having high affinity with microorganism and heavy metals.

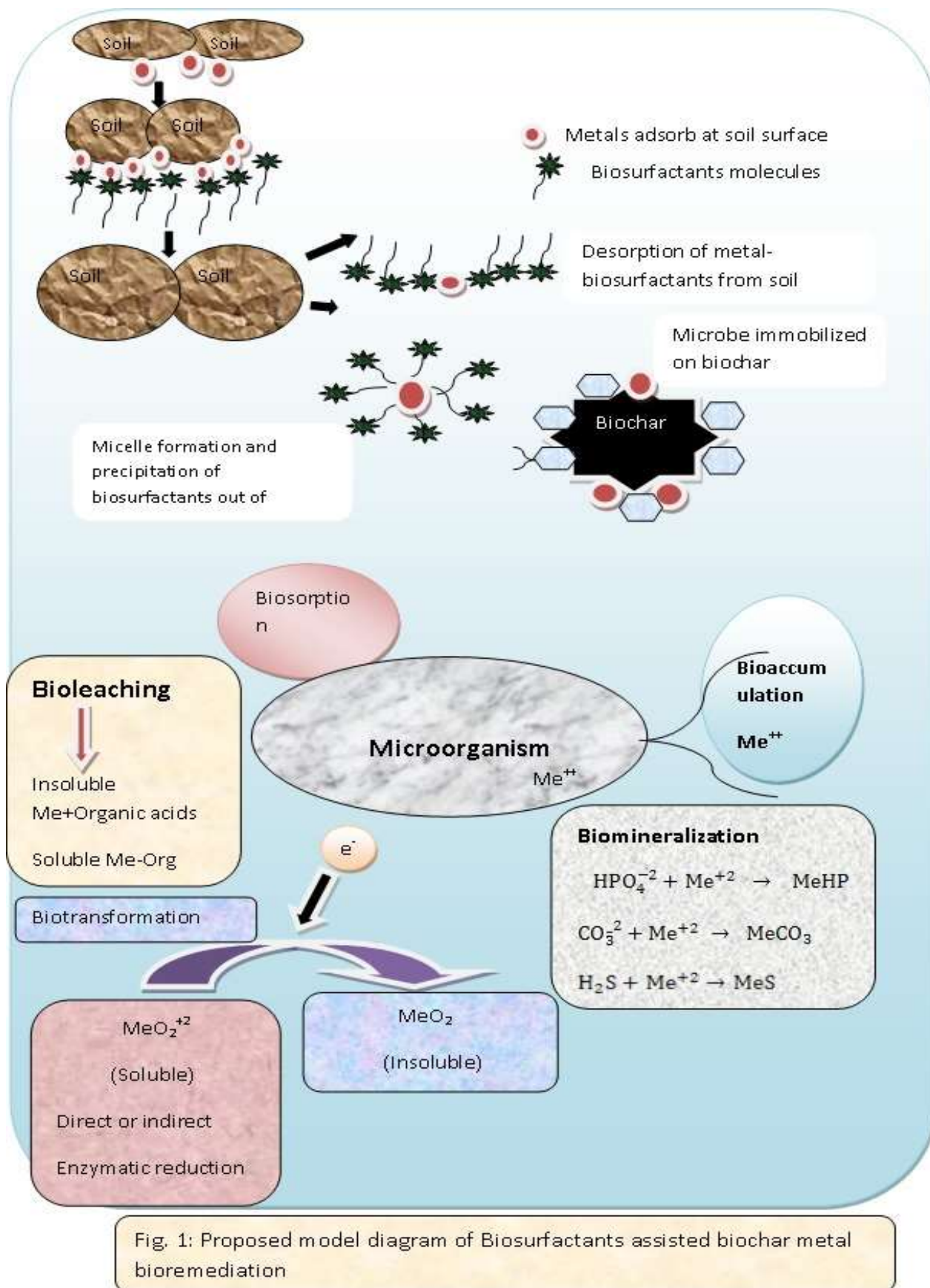
Biochar formed by pyrolyzing biomass under oxygen limited conditions are a class of carbonized organic materials (COM) which contain both non carbonized organic matter (COM) and carbonized organic matter (NCOM) (Chen et al., 2008; Chen et al., 2009). Due to recalcitrant to decomposition biochar application increase soil carbon pool and soil health. Biochar were suggested as immobilized carrier for nutrients (Beck 1991; Chen et al. 2011a) and microorganisms as well. The proposed conceptual diagram (Fig. 1) shows the mechanism how microorganisms immobilized on biochar significantly enhance the bioremediation process.

3.6 Biosurfactant assistance in removal of heavy metals

Bioremediation of metal-contaminated soils is more complex because microbial cells or large exopolymers do not move freely through the soil. The use of microbiologically produced

surfactants (biosurfactants) is an alternative with potential for remediation of metal-contaminated soils. The distinct advantage of biosurfactants over whole cells or exopolymers is their small size, generally biosurfactant molecular weights are less than 1500. A second advantage is that biosurfactants have a wide variety of chemical structures that may show different metal selectivities and thus, metal removal efficiencies. Rhamnolipid are most common biosurfactants in which one or two molecules of rhamnose are linked to one or two molecules of β -hydroxydecanoic acid are the best-studied glycolipids. Production of rhamnose-containing glycolipids was first described in *Pseudomonas species*.

Biosurfactants have the potential to impact the major factors that cause the removal of heavy metals from soils to be so difficult, namely, sorption, rate-limited mass transfer, and resistance to aqueous-phase transport. The addition of a biosurfactant may promote desorption of heavy metals from solid phases in two ways. The first is through complexation of the free form of the metal residing in solution. This decreases the solution phase activity of the metal and, therefore, promotes desorption according to Le-Chatelier's principle. The second is that under conditions of reduced interfacial tension, biosurfactants will accumulate at the solid-solution interface. This may allow direct contact between the biosurfactant and the sorbed metal. (Miller, 1995). The proposed diagram (Fig. 1) illustrates how biosurfactants facilitate in making available heavy metals to the immobilized microbial cells on biochar in remediation process. These include adsorption of micelle on soil surface, interaction with sorbed metal, desorption of surfactant and metal, transportation of metal and surfactant away from the soil, incorporation of the metal into micelle, precipitation of biosurfactants out of the complex and availability of heavy metals for microbial cells immobilized on biochar. The later mechanisms how microorganisms interact with heavy metals depend upon the concentration and speciation of heavy metals.



4. Conclusion

Application of biochar reversed the toxic effects of different heavy metals stress. Biochar is viable approach to remediate the heavy metals containing soil. So, biochar is possibly a good substitute in current culture to resolve ecological and foodstuff difficulties confronted by the fast evolving society and quick growing population. In spite of so much research, obviously more investigation is required to form full potential of biochar as a technology with theoretically several advantages to the atmosphere. Numerous information breaks have been acknowledged, and more study is vital to close by these gaps. This approach could be very effective to enhance the remediation of heavy metals from the polluted soil but further work is needed to know the mechanism involved various important investigation essentials are discussed below.

In forthcoming years, we can use biochar and phytoremediation as joint strategies to address heavy metal pollution. Further with this the progress on fertilizers that are based on biochar, can be used for modification of the existing pattern of soil heavy metal remediation, and thus reduced contaminant immobilization. One more imminent research track for this type of studies could be to use phytoremediators and biochars directing at different heavy metals. Biochar reduces the bioavailability and leach ability of heavy metals in the soil. While phytoextractors reduce the quantity of soil heavy metals in contaminated zones. In coming years there will be an increasing attention to investigate the relations between biochars and phytoremediators and these areas can be one of the demanding investigation. An extensive study is mandatory to regulate the prominence of the different biochar features implying in soil CO₂ discharges. In reality, owing to aging functions, biochar capability to sequester heavy metals reduces with passage of time. New investigations are required to recognize the aging procedure in biochar.

References

- Abdullah, H. and Wu, H. 2009. Biochar as a fuel: Properties and grind ability of biochars produced from the pyrolysis of mallee wood under slow-heating conditions. *Energy and Fuels* 23: 4174-4181.
- Agblevor, F. A., Beis, S., Kim, S. S., Tarrant, R. & Mante, N. O. 2010. Biocrude oils from the fast pyrolysis of poultry litter and hardwood. *Waste Management* 30: 298-307.

- Ahmad M, Soo Lee S, Yang JE, Ro HM, Han Lee Y, Ok YS. 2012. Effects of soil dilution and amendments (mussel shell, cow bone, and biochar) on Pb availability and phytotoxicity in military shooting range soil. *Ecotoxicol. Environ. Saf.* 79:225-231.
- Amonette, J.E., Joseph, S., 2009. Characteristics of Biochar: Micro chemical Properties. In: J. Lehmann, Joseph, S. (Editor), *Biochar for Environmental Management Science and Technology*. Earth scan, London.
- Antal, M., Gronli, M., 2003. The art, science and technology of charcoal production. *Industrial engineering chemistry research* 42: 1619-1640.
- Asai, H., Samson, B. K., Stephan, H. M., Songyikhangsuthor, K., Homma, K., Kiyono, Y., Inoue, Y., Shiraiwa, T., and Horie, T. 2009. Biochar amendment techniques for upland rice production in Northern Laos 1. Soil physical properties, leaf SPAD and grain yield, *Field Crop Res.* 111: 81-84.
- 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 and Soil* 337: 1-18.
- Baiamonte, G., C. De Pasquale, V. Marsala, G. Cimò, G. Alonzo, G. Crescimanno and P. Conte. 2015. Structure alteration of a sandy-clay soil by biochar amendments. *J. Soils Sediments.* 15: 816–824.
- Baldock, J.A, R.J, Smernik. 2002. Chemical composition and bioavailability of thermally altered Beck DP (1991) Suitability of charcoal-amended mineral soil as carrier for rhizobium inoculants. *Soil Biol Biochem* 23:41–44
- Beesley L, Moreno-Jiménez E, Gomez-Eyles J L. 2010. Effects of biochar and greenwaste compost amendments on mobility, bio-availability and toxicity of inorganic and organic contaminants in a multi-element polluted soil. *Environ. Pollut.* 158:2282-2287.
- Beesley L, Moreno-Jiménez E, Gomez-Eyles JL, Harris E, Robinson B, Sizmur T. 2011. A review of biochars' potential role in the remediation, revegetation and restoration of contaminated soils. *Environ. Pollut.* 159:3269-3282.
- Beesley, L. and Marmiroli, M. 2011. The immobilisation and retention of soluble arsenic, cadmium and zinc by biochar, *Environ. Pollut.* 159: 474-480.
- Beesley, L., Marmiroli, M., Pagano, L., Pignoni, V., Fellet, G., Fresno, T., Vamerali, T., Bandiera, M., and Marmiroli, N. 2013. Biochar addition to an arsenic contaminated soil increases ar-

- senic concentrations in the pore water but reduces uptake to tomato plants (*Solanum lycopersicum* L.). *Sci. Total Environ.* 454-455, 598-603.
- Berglund, L.M., T.H. DeLuca and O. Zackrisson. 2004. Activated carbon amendments to soil alters nitrification rates in Scots pine forests. *Soil Biology & Biochemistry.* 36:2067- 2073.
- Biana, Chena. D, Xiaoyu. L, Cui. L, Li. L, Pana. G, Xiea. D, Zhenga. J, Zhanga. X, Chang. A. 2013. Biochar soil amendment as a solution to prevent Cd-tainted rice from China: Results from a cross-site field experiment. *Ecol. Engin.* 58: 378-383.
- Bird, M. I., Ascough, P. L., Young, I. M., Wood, C. V. & Scott, A. C. 2008. X-ray microtomographic imaging of charcoal. *Journal of Archaeological Science.* 35: 2698-2706.
- Bridle, T. R., and Pritchard, D. 2004. Energy and nutrient recovery from sewage sludge via pyrolysis. *Water Sci. Technol.* 50: 169-175.
- Brockhoff, S.R., Christians, N.E., Killorn, R.J., Horton, R., Davis, D.D., 2010. Physical and mineral-nutrition properties of sand-based turfgrass root zones amended with biochar. *Agronomy Journal* 102: 1627-1631
- Brodowski, S.; Amelung, W.; Haumaier, L.; Abetz, C. Zech, W. 2005. Morphological and chemical properties of black carbon in physical soil fractions as revealed by scanning electron microscopy and energy-dispersive x-ray spectrometry. *Geoderma.* 128:116-129.
- Brownsort, P. A. 2009. Biomass pyrolysis processes: Performance parameters and their influence on biochar system benefits. Edinburgh: UK Biochar Research Centre - SCCS Consortium, 2009. A dissertation presented for the degree of Master of Science University of Edinburgh, 2009.
- Busscher, W., Novak, J.M., Ahmedna, M., 2011. Physical effects of organic matter amendment of a southeastern US coastal loamy sand. *Soil Science* 176: 661-667.
- Cao XD, Harris W. 2010. Properties of dairy-manure-derived biochar pertinent to its potential use in remediation. *Bioresou. Technol.* 101:5222-5228.
- Cao, X., Ma, L., Gao, B. & Harris, W. 2009. Dairy-manure derived biochar effectively sorbs lead and atrazine. *Environmental Science and Technology* 43: 3285-3291.
- Cassidy MB, Lee H, Trevors JT (1996) Environmental applications of immobilized microbial cells: a review. *J Indust Microbiol* 16:79–101.

- Chan, K.Y., and Z. Xu. 2009. Biochar: Nutrient properties and their enrichment. pp.67-84. In J. Lehmann and S. Joseph (eds.) Biochar for environmental management: Science and technology. Earthscan, London.
- Chen BL, Chen ZM (2009) Sorption of naphthalene and 1-naphthol by biochars of orange peels with different pyrolytic temperatures. *Chemosphere* 76:127–133
- Chen BL, Chen ZM, Lv SF (2011a) A novel magnetic biochar efficiently sorbs organic pollutants and phosphate. *Bioresour Technol* 102(2):716–723
- Chen BL, Chen ZM, Lv SF (2011a) A novel magnetic biochar efficiently sorbs organic pollutants and phosphate. *Bioresour Technol* 102(2):716–723
- Chen BL, Zhou DD, Zhu LZ (2008) Transitional adsorption and partition of nonpolar and polar aromatic contaminants by biochars of pine needles with different pyrolytic temperatures. *Environ Sci Technol* 42:5137–5143
- Chen, B. & Yuan, M. 2011. Enhanced sorption of polycyclic aromatic hydrocarbons by soil amended with biochar. *Journal of Soils and Sediments* 11: 62-71.
- Cheng CH, Lehmann J, Thies J E, Burton SD, Engelhard MH. 2006. Oxidation of black carbon by biotic and abiotic processes. *Organ Geochem* 37:1477-1488.
- Cheng, C.H.; Lehmann, J.; Engelhard, M.H. 2008. Natural oxidation of black carbon in soils: changes in molecular form and surface charge along a climosequence. *Geochim. Cosmochim. Acta.* 72: 1598-1610.
- Choppala GK, Bolan NS, Megharaj M, Chen Z, Naidu R. 2012. The influence of biochar and black carbon on reduction and bioavailability of chromate in soils. *J. Environ. Qual.* 41:1175-1184.
- Cui, L., Pan, G., Li, L., Yan, J., Zhang, A., Bian, R., and Chang, A. 2012. The reduction of wheat Cd uptake in contaminated soil via biochar amendment: A two-year field experiment, *Bioresources.* 7: 5666-5676.
- Cummer, K. R., and R. C. Brown. 2002. Ancillary equipment for biomass gasification. *Biomass and Bioenergy* 23:113-128.
- Cunningham CJ, Ivshina IB, Lozinsky VI, Kuyukina MS, Philp JC (2004) Bioremediation of diesel-contaminated soil by microorganisms immobilised in polyvinyl alcohol. *Int Biodeter Biodegr* 54:167–174

- Debela F, Thring RW, Arocena JM. 2012. Immobilization of heavy metals by co-pyrolysis of contaminated soil with woody biomass. *Water Air Soil Pollut* 223:1161-1170.
- Deenik, J., Diarra, A., Uehara, G., Campbell, S., Sumiyoshi, Y., Antal Jr., M., 2011. Charcoal ash and volatile matter effects on soil properties and plant growth in an acid Ultisol. *Soil Science* 176: 336-345.
- DeLuca, T. H., MacKenzie, M. D., and Gundale, M. J. 2009. Biochar effects on soil nutrient transformations. In “Biochar for Environmental Management: Science and Technology” (J. Lehmann and S. Joseph, Eds.), Earthscan, London.
- DeLuca, T. H., MacKenzie, M.D., Gundale, M. J. and Holben, W. E. 2006. Wildfire-produced charcoal directly influences nitrogen cycling in forest ecosystems. *Soil Science Society America Journal*, vol 70: 448-453.
- Devi. P, and Saroha. A. K. 2014. Risk analysis of pyrolyzed biochar made from paper mill effluent treatment plant sludge for bioavailability and eco-toxicity of heavy metals. *Biores. Technol.* 162: 308-315.
- Ding, Y., Liu, Y., Wu, W., Shi, D., Yang, M., Zhong, Z., 2010. Evaluation of biochar effects on nitrogen retention and leaching in multi-layered soil columns. *Water Air and Soil Pollution* 213: 47-55.
- Ding, Y., Y. Liu, S. Liu, Z. Li, X. Tan, X. Huang and B. Zheng. 2016. Biochar to improve soil fertility. A review. *Agronomy for Sustainable Development*. 36(2): 1-18.
- Downie, A., A. Crosky, and P. Munroe. 2009. Physical properties of biochar. pp. 13-32. In J. Lehmann and S. Joseph (eds.) *Biochar for environmental management: Science and technology*. Earthscan, London.
- Dzul-Puc JD, Esparza-Garcia F, Barajas-Aceves M, Rodriguez-Vazquez R (2005) Benzo[*a*]pyrene removal from soil by *Phanerochaete chrysosporium* grown on sugarcane bagasse and pine sawdust. *Chemosphere* 58:1–7
- Elad, Y., Cytryn, E., Harel, Y. M., Lew, B., and Graber, E. R.: 2011. The biochar effect: plant resistant to biotic stresses, *Phytopathol. Mediterr.* 50: 335-349.
- Elad, Y., David, D. R., Harel, Y. M., Borenshtein, M., Kalifa, H. B., Silber, A., and Graber, E. R.: 2010. Induction of systemic resistance in plants by biochar, a soil-applied carbon sequestering agent, *Phytopathology*. 100: 913-921.

- Esteves, B.M.; Pereira, H.M. 2009. Wood modification by heat treatment: A review. *Bioresour.*4: 370-404.
- Fellet G, Marchiol L, Delle Vedove G, Peressotti A. 2011. Application of biochar on mine tailings: effects and perspectives for land reclamation. *Chemosphere* 83:1262-1297.
- Fuertes, A. B., Arbestain, M. C., Sevilla, M., Maclá-Agulló, J. A., Fiol, S., López, R., Smernik, R. J., Aitkenhead, W. P., Arce, F. and Maclas, F. 2010. Chemical and structural properties of carbonaceous products obtained by pyrolysis and hydrothermal carbonisation of corn stover. *Australian Journal of Soil Research* 48: 618-626.
- Fushimi, C.; Araki, K.; Yamaguchi, Y.; Tsutsumi, 2003. A. Effect of heating rate on steam gasification biomass. 2. Thermogravimetric-mass spectrometric (TG-MS) analysis of gas evolution. *Ind. Eng. Chem. Res.*42: 3929-2936.
- Gadepalle, V. P., Ouki, S. K., Van Herwijnen, R. & Hutchings, T. 2007. Immobilization of heavy metals in soil using natural and waste materials for vegetation establishment on contaminated sites. *Soil and Sediment Contamination* 16: 233-251.
- Gascó, G., Paz-Ferreiro, J. and Méndez. 2012. A Thermal analysis of soil amended with sewage sludge and biochar from sewage sludge pyrolysis, *J. Therm. Anal. Calorim.* 108: 769-775.
- Gaskin, J.W., R.A. Speir, K. Harris, K.C. Das, R.D. Lee, L.A. Morris and D.S. Fisher. 2010. Effect of Peanut Hull and Pine Chip Biochar on Soil Nutrients, Corn Nutrient Status, and Yield. *Agronomy Journal.* 102:623-633.
- González, J. F., Román, S., Encinar, J. M., Martínéz, G., 2009. pyrolysis of various biomass residues and char utilization for the production of activated carbons. *Journal of Analytical and Applied Pyrolysis* 85: 134-141.
- Graber, E.R., Tsechansky, L., Lew, B. & Cohen, E. 2014. Reducing capacity of water extracts of biochars and their solubilization of soil Mn and Fe. *European Journal of Soil Science*, 65
- Hammes, K., and Schmidt, M. W. I. 2009. Changes of biochar in soil. In “Biochar for Environmental Management: Science and Technology” (J. Lehmann and S. Joseph, Eds.), Earthscan, London.169-181.
- Hartley, W., Dickinson, N. M., Riby, P. & Lepp, N. W. 2009. Arsenic mobility in brownfield soils amended with green waste compost or biochar and planted with miscanthus. *Environ. Pollut.* 157: 2654-2662.

- Houben D., E. Laurent and S. Philippe. 2013. Mobility, bioavailability and pH-dependent leaching of cadmium, zinc and lead in a contaminated soil amended with biochar. *Chemosphere*. 92: 1450-1457.
- James, G.; Sabatini, D.A.; Chiou, C.T.; Rutherford, D.; Scott, A.C.; Karapanagioti, H.K. 2005. Evaluating phenanthrene sorption on various wood chars. *Water. Res.* 39: 549-55.
- Jeffery S, Verheijen FGA, van der Velde M, Bastos AC. 2011. A quantitative review of the effects of biochar application to soils on crop productivity using metaanalysis. *Agri. Ecos. Environ.* 144:175-187.
- Jiang, J., Xu, R. K., Jiang, T. Y., and Li, Z. 2012. Immobilization of Cu(II), Pb(II) and Cd(II) by the addition of rice straw derived biochar to a simulated polluted Ultisol, *J. Hazard. Mater.* 229-230, 145–150.
- Jones, S.B., J.E. Holladay, C. Valkenburg, D.J. Stevens, C.W. Walton, C. Kinchin, D.C. Elliott, S. Czernik. 2009. Production of Gasoline and Diesel from Biomass via Fast Pyrolysis, Hydrotreating and Hydrocracking: A Design Case. U.S. Department of Energy, Contract DE-AC05-76RL01830.
- Kammann, C.I., H.P. Schmidt, N. Messerschmidt, S. Linsel, D. Steffens, C. Müller, H.W. Koyro, P. Conte and S. Joseph. 2015. Plant growth improvement mediated by nitrate capture in co-composted biochar. *Sci. Report* 5: 11080.
- Karagöz, S.; Bhaskar, T.; Muto, A.; Sakata, Y.; Oshiki, T.; Kishimoto, T. 2005. Low-temperature catalytic hydrothermal treatment of wood biomass: Analysis of liquid products. *Chem. Eng. J.* 108: 127-137.
- Kawamoto, K.; Ishimaru, K.; Imamura, Y. 2005. Reactivity of wood charcoal with ozone. *J. Wood Sci.* 51: 66-72.
- Keiluweit, M. P. S. Nico, M. Johnson, and M. Kleber. 2010. “Dynamic molecular structure of plant biomass-derived black carbon (biochar),” *Environmental Science and Technology*, vol. 44, no.4: 1247-1253.
- Kim, H.S., K.R. Kim, H.J. Kim, K.H. Kim, J.E. Yang, Y.S. Ok, G. Owens. 2015. Effect of biochar on heavy metal immobilization and uptake by lettuce (*Lactuca sativa* L.) in agricultural soil *Environ. Earth Sci.* 74 (2): 1–11.

- Kookana RS, Sarmah AK, Van Zwieten L, Krull E, Singh B. 2011. Biochar application to soil: agronomic and environmental benefits and unintended consequences. In: Sparks DL (ed) *Adv Agro*. 112:103-143.
- Krull, E.S., J.A. Baldock, J.O. Skjemstad, and R.J. Smernik. 2009. Characteristics of biochar: Organo chemical properties. 53-65. In J. Lehmann and S. Joseph (eds.) *Biochar for environmental management: Science and technology*. Earthscan, London.
- Kumar, A., Schreiter, I.J., Wefer-Roehl, A., Schüth, C., Graber, E.R. 2016. Environmental Materials and Waste: Resource Recovery and Pollution Prevention 91: 116.
- Kumpiene J. 2010. Trace element immobilization in soil using amend-ments. In: Hooda P (ed) *Trace elements in soils*. Wiley, Wiltshire. 353-380.
- Laird, D., Fleming, P., Wang, B., Horton, R., Karlen, D., 2010. Biochar impact on nutrient leaching from a midwestern agricultural soil. *Geoderma* 158: 436-442.
- Laird, D.A., R.C. Brown, J.E. Amonette, and J. Lehmann. 2009. Review of the pyrolysis platform for co-producing bio-oil and biochar. *Biofuels, Bioprod. Bioref.* 3:547-562.
- Lal, R. (2009) Challenges and opportunities in soil organic matter research. *European Journal of Soil Science* 60, 158-169.
- Lee WJ, Shih SI, Chang CY, Lai YC, Wang LC, Chang-Chien GP. 2008. Thermal treatment of polychlorinated dibenzo-p-dioxins and dibenzofurans from contaminated soils. *J Hazard Mater* 160:220-227.
- Lehmann, J. 2007. A handful of carbon. *Nature*. 447: 143-144.
- Lehmann, J. and Joseph, S. 2009. *Biochar for environmental management: science and technology*. Earthscan, London and Sterling, VA USA.
- Lehmann, J. and M. Rondon. 2006. Bio-char soil management on highly weathered soils in the humid tropics. In *Biological Approaches to Sustainable Soil Systems* Ed. N. Uphoff. CRC Press, Boca Raton , FL. 517-530.
- Lehmann, J., Gaunt, J., Rondon, M. 2006. Bio-char sequestration in terrestrial ecosystems. a review. *Mitigation and Adaption Strategies for Global Change* 11: 403-427.
- Lei, H., Ren, S. & Julson, J. 2009. The effects of reaction temperature and time and particle size of corn stover on microwave pyrolysis. *Energy and Fuels* 23: 3254-3261.

- Liang, B., Lehmann, J., Solomon, D., Kinyangi, J., Grossman, J., O'Neill, B., Skjemstad, J.O., Thies, J., Luiza, F.J., Petersen, J., Neves, E.G. 2006. Black carbon increases cation exchange capacity in soils. *Soil Sci. Soc. Am. J.* 70: 1719-1730.
- Liu YX, Yang M, Wu YM, Wang HL, Chen YX, Wu WX. 2011. Reducing CH₄ and CO₂ emissions from water logged paddy soil with biochar. *J Soils Sediments* 11:930-939.
- Liu, X., Zhang, A., Ji, C., Joseph, S., Bian, R., Li, L., Pan, G., and Paz-Ferreiro, J. 2013. Biochar's effect on crop productivity and the dependence on experimental conditions- a meta-analysis of literature data, *Plant Soil*, 373: 583-594.
- Lu H, Li Z, Fu S, Mendez A, Gasco G, *et al.* 2014. Can Biochar and Phytoextractors Be Jointly Used for Cadmium Remediation? *PLoS ONE* 9(4): e95218. doi:10.1371/journal.pone.0095218.
- Lu, H., Zhang, Y. Y., Huang, X., Wang, S., and Qiu, R. 2012. Relative distribution of Pb²⁺ sorption mechanisms by sludge-derived biochar. *Water Res.*, 46: 854-862.
- Lu, K., X. Yang, J. Shen, B. Robinson, H. Huang, D. Liu, N. Bolan, J. Pei, H. Wang. 2014. Effect of bamboo and rice straw biochars on the bioavailability of Cd, Cu, Pb and Zn to *Sedum plumbizincicola*. *Agric. Ecosyst. Environ.* 191: 124–132.
- Lu, S.G., F.F. Sun, Y.T. Zong. 2014. Effect of rice husk biochar and coal fly ash on some physical properties of expansive clayey soil (Vertisol). *Catena.* 114: 37–44.
- Lua. K, Yang. X, Shenb. J, Robinsonc. B, Huang. H, Liua. D, Bolane. N, Pei. J, Wanga. H. 2014. Effect of bamboo and rice straw biochars on the bioavailability of Cd, Cu, Pb and Zn to *Sedum plumbizincicola*. *Agriculture, Ecosystems and Environment* 191: 124-132.
- Mahinpey, N., Murugan, P., Mani, T. & Raina, R. 2009. Analysis of bio-oil, biogas, and biochar from pressurized pyrolysis of wheat straw using a tubular reactor. *Energy and Fuels* 23: 2736-2742.
- Maiti, S.; Dey, S.; Purakayastha, S.; Ghosh, B. 2006. Physical and thermochemical characterization of rice husk char as a potential biomass source. *Bioresour. Technol.* 97: 2065-2070.
- Major, J., Lehmann, J., Rondon, M., Goodale, C. 2010. Fate of soil-applied black carbon: downward migration, leaching and soil respiration. *Global Change Biol.* 16: 1366-1379.

- Major, J., Lehmann, J., Rondon, M., Goodale, C. 2010a. Fate of soil-applied black carbon: Downward migration, leaching and soil respiration. *Global Change Biology* 16: 1366-1379.
- Marris, E., 2006. Putting the carbon back: Black is the new green. *Nature* 442(7103): 624-626.
- Martínez, M. L., Torres, M. M., Guzmán, C. A., Maestri, D. M., 2006. Preparation and characteristics of activated carbon from olive stones and walnut shells. *Industrial crops and products* 23: 23-28.
- McHenry, M. P. 2008. Agricultural bio-char production, renewable energy generation and farm carbon sequestration in Western Australia: Certainty, uncertainty and risk. *Agric. Ecosystems Environ.*, 129:1-7.
- Mench M, Lepp N, Bert V, Schwitzguébel J-P, Gawronski SW, Schöder P, Vangronsveld J. 2010. Successes and limitations of phytotechnologies at field scale: outcomes, assessment and out-look from COST action 859. *J Soils Sediments* 10:1039-1070.
- Méndez A, Gómez A, Paz-Ferreiro J, Gascó G .2012. Effects of sewage sludge biochar on plant metal availability after application to a Mediterranean soil. *Chemosphere* 89:1354-1359
- Miller, R. M. (1995). Biosurfactant-facilitated remediation of metal-contaminated soils. *Environmental health perspectives*, 103(Suppl 1), 59.
- Mohammadi A, Enayatzadeh M, Nasernejad B (2009) Enzymatic degradation of anthracene by the white rot fungus *Phanerochaete chrysosporium* immobilized on sugarcane bagasse. *J Hazard Mater* 161:534–537
- Mohan D., C.U. Pittman, and P.H. Steele. 2006. Pyrolysis of Wood/Biomass: A critical review. *Energy & Fuels*, 20: 848-889.
- Molina, M., Zaelke, D., Sarma, K. M., Andersen, S. O., Ramanathan, V and Kaniaru, D. 2009. Reducing abrupt climate change risk using the montreal protocol and other regulatory actions to complement cuts in CO₂ emissions. *Proceedings of the National Academy of Sciences of the United States of America*. 106: 20616-20621.
- Mullen, C.A., A.A. Boateng, N. Goldberg, I.M. Lima, D.A. Laird, and K.B. Hicks. 2010. Bio-oil and bio-char production from corn cobs and stover by fast pyrolysis. *Biomass Bioenergy*, 34: 67-74.
- Naidu R, Semple KT, Megharaj M, Juhasz AL, Bolan NS, Gupta S, Clothier B, Schulin R, Chaney R. 2008. Bioavailability, definition, assessment and implications for risk assessment. In:

- Naidu R, *et al.* (eds) Chemical bioavailability in terrestrial environment. Elsevier, Amsterdam, pp 39-52. ISBN: 978-0-444-52
- Namgay T, Singh B, Singh BP. 2010. Influence of biochar application to soil on the availability of As, Cd, Cu, Pb, and Zn to maize (*Zea mays* L.). *J Aust. Soil. Res.* 48:638-647.
- Nelissen, V., G. Ruyschaert, D. Manka'Abusi, T. D'Hose, K. De Beuf, B. Al-Barri, W. Cornelis, P. Boeckx. 2015. Impact of a woody biochar on properties of a sandy loam soil and spring barley during a two-year field experiment. *Eur. J. Agron.* 62: 65–78.
- Novak, J.M., Busscher, W.J., Laird, D.L., Ahmedna, M., Watts, D.W., Niandou, M.A.S., 2009. Impact of biochar amendment on fertility of a southeastern coastal plain soil. *Soil Science* 174, 105-112.
- Nuopponen, M.; Vuorinen, T.; Jamsa, S.; Viitaniemi, P. 2004 Thermal modifications in softwood studied by FT-IR and UV resonance Raman spectroscopies. *J. Wood Chem. Technol.* 24:13-26.
- Park JH, Choppala GK, Bolan NS, Chung JW, Chuasavathi T. 2011. Biochar reduces the bioavailability and phytotoxicity of heavy metals. *Plant Soil* 348: 439-451.
- Park, J. H., Choppala, G. H., Lee, S. J., Bolan, N., Chung, J. W., and Edraki, M. 2013. Comparative sorption of Pb and Cd by biochars and its implication for metal immobilization in soil. *Water. Air. Soil. Poll.* 224: 1711, doi:10.1007/s11270-013-1711-1.
- Paz-Ferreiro, J., Fu, S., Méndez, A., and Gasco, G.: Interactive effects of biochar and the earthworm *Pontoscolex corethrurus* on plant productivity and soil enzymes activities, *J. Soils Sediments*, doi:10.1007/s11368-013-0806-z, in press, 2014.
- Peng, X., Ye, L. L., Wang, C.H., Zhou, H., and Sun, B. 2011. Temperature- and duration-dependent rice straw-derived biochar: characteristics and its effects on soil properties of an Ultisol in southern China, *Soil Till. Res.* 11: 159-166.
- Pinus resinosa* (red pine) wood. *Org. Geochem.* 33: 1093-1109.
- Puga, A.P., C.A. Abreu, L.C.A. Melo, J. Paz-Ferreiro, L. Beesley. 2015. Cadmium, lead, and zinc mobility and plant uptake in a mine soil amended with sugarcane straw biochar. *Environ. Sci. Pollut. Res.* 1–9.
- Rahman, R. N. Z, F. M. Ghazali, A. B. Salleh and M. Basri, J. 2006. *Microbiol*, 44 : 354.

- Rees, F., M. O. S. imonnot and J. L. Morel. 2014. Short-term effects of biochar on soil heavy metal mobility are controlled by intra-particle diffusion and soil pH increase. *European Journal of Soil Science*. 65: 149-161.
- Roy, M. and McDonald, L. M.: Metal uptake in plants and health risk assessments in metal contaminated smelter soils, *Land De-grad. Dev.* doi:10.1002/ldr.2237, in press, 2014.
- Schmidt, H.P., B.H. Pandit, V. Martinsen, G. Cornelissen, P. Conte, C.I. Kammann. 2015. Fourfold increase in pumpkin yield in response to low-dosage root zone application of urine-enhanced biochar to a fertile tropical soil. *Agriculture*. 5: 723–741.
- Schmidt, M. W. I., and Noack, A. G. 2000. Black carbon in soils and sediments: Analysis, distribution, implications and current challenges. *Glob. Biogeochem. Cycle* 14: 777-793.
- Singh, B., Singh, B. P., and Cowie, A. L. 2010b. Characterisation and evaluation of biochars for their application as a soil amendment. *Aust. J. Soil Res.* 48: 516-525.
- Six, J., Bossuyt, H., Degryze, S., Deneff, K. 2004. A history of research on the link between (micro) aggregates, soil biota, and soil organic matter dynamics. *Soil. Till. Res.* 79: 7-31.
- Sohi, S., E. Krull, E. Lopez-Capel, and R. Bol. 2010. A review of biochar and its use and function in soil. *Adv. Agron.* 105:47-82.
- Sohi, S.; Lopez-Capel, E.; Krull, E.; Bol, R. *Biochar, Climate Change and Soil: A Review to Guide Future Research*; CSIRO Land and Water Science Report 05/09; CSIRO Publishing: Melbourne, Australia, 2009; pp. 5-6.
- Solaiman, Z. M., Blackwell, P., Abbott, L. K., and Storer, P. 2010. Direct and residue effect of biochar application on mycorrhizal root colonisation, growth and nutrition of wheat. *Aust. J. Soil Res.* 48: 546-554.
- Steinbeiss, S., Gleixner, G. & Antonietti, M. 2009. Effect of biochar amendment on soil carbon balance and soil microbial activity. *Soil Biology and Biochemistry* 41: 1301-1310.
- Steiner, C., Das, K., Garcia, M., Forster, B., Zech, W., 2008a. Charcoal and smoke extract stimulate the soil microbial community in a highly weathered xanthic ferralsol. *Pedobiologia* 51: 359-366.
- Su D, Li PJ, Stagnitti F, Xiong XZ (2006) Biodegradation of benzo[*a*]pyrene in soil by *Mucor* sp. SF06 and *Bacillus* sp. SB02 co-immobilized on vermiculite. *J Environ Sci-China* 18:1204–1209

- Sun K, Gao B, Ro KS, Novak JM, Wang ZY, Herbert S, Xing B.S. 2012. Assessment of herbicide sorption by biochars and organic matter associated with soil and sediment. *Environ Pollut* 163:167-173.
- Suppadit T, Kitikoon V, Phubphol A, Neumnoi P. 2012. Effect of quail litter biochar on productivity of four new physic nut varieties planted in cadmium-contaminated soil. *Chilean. J. Agric. Res.* 72: 125-132.
- Tenenbaum, D. J. 2009. Biochar: Carbon mitigation from the ground up. *Environmental Health. Perspectives.* 117: 2.
- Thies, E., and Rilling, M. C. 2009. Characteristics of biochar: Biological properties. In “Biochar for Environmental Management. Science and Technology” (J. Lehmann and S. Joseph, Eds.), Earthscan, London.
- Uchimiya, M., Chang, S. C., and Klasson, K. T. 2011c. Screening biochars for heavy metal retention in soil: Role of oxygen functional groups, *J. Hazard. Mater.* 190: 432-444.
- Vacca, A., Bianco, M. R., Murolo, M., and Violante, P. 2012. Heavy metals in contaminated soils of the Rio Sitzerri floodplain (Sardinia, Italy): Characterization and impact on pedodiversity, *Land De-grad. Dev.*, 23: 250-364.
- Van Herwijnen, R., Hutchings, T. R., Al-Tabbaa, A., Moffat, A. J., Johns, M. L. & Ouki, S. K. 2007. Remediation of metal contaminated soil with mineral-amended composts. *Environ. Pollution.* 150, 347-354.
- Van Zwieten, L., Kimber, S., Downie, A., Joseph, F., Chan, K. Y., Cowie, A., Wainberg, R., and Morris, S., 2007. Paper mill char: benefits for soil health and plant production. Proceedings, International Agri char Initiative Conference, 30th April - 2nd May 2007, Terrigal, Australia.
- Verheijen, F.; 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 240099 EN; Office for the Official Publications of the European Communities: Luxembourg. 1-149.
- Verheijen, F.G.A., Jeffery, S., Bastos, A.C., van der Velde, M., Diafas, I., 2010. Biochar application to soils, A critical scientific review of effects on soil properties, processes and functions. EUR 24099 EN,

- Wagner, A. & Kaupenjohann, M. 2014. Suitability of biochars (pyro- and hydrochars) for metal immobilization on former sewage-field soils. *European Journal of Soil Science*, 65.
- Wang H, Lin K, Hou Z, Richardson B, Gan J. 2010. Sorption of the herbicide terbuthylazine in two New Zealand forest soils amended with biosolids and biochars. *J. Soils Sediments* 10: 283-289.
- Warnock, D.D., Lehmann, J., Kuyper, T.W., Rillig, M.C. 2007. Mycorrhizal responses to biochar in soil – concepts and mechanisms. *Plant Soil* 300: 9-20.
- Weyers, S. L., Gaskin, J., Liesch, A. M., and Das, K. C. 2010. Earthworms, microbes and the release of c and n in biochar amended soil. In “Proceedings of the 2010 U.S. Biochar Initiative Conference, June 27–30, 2010, Ames, Iowa”
- Windeisen, E.; Wegener, G. 2008. Behaviour of lignin during thermal treatments of wood. *Ind. Crops Products*. 27: 157-162.
- Xu X, Cao X, Zhao L, Wang H, Yu H, Gao B. 2013. Removal of Cu, Zn, and Cd from aqueous solutions by the dairy manure derived biochar. *Environ. Sci. Pollut. Res.* 20: 358-368.
- Yang, D., Zeng, D. H., Li, L. J., and Mao, R. 2012. Chemical and micro-bial properties in contaminated soils around a magnesite mine in Northeast China, *Land Degrad. Dev.* 23: 256-262.
- Yanik, J., Kommayer, C., Saglam, M., Yuksel, M. 2007. Fast pyrolysis of agricultural wastes: Characterization of pyrolysis products. *Fuel Processing Technology* 88: 942-947.
- Yin Chan, K., Xu, Z., 2009. Biochar: nutrient properties and their enhancement. In: Lehmann, J., Joseph, S. (Eds.), *Biochar for Environmental Management*. Earth-scan, U.S.A
- Yu, X. Y., Ying, G. -G. and Kookana, R. S. 2006. Sorption and desorption behaviour of diuron in soil amended with charcoal. *Journal of Agricultural and Food Chemistry* 54: 8545-8550.
- Yu, X., Pan, L., Ying, G. & Kookana, R.S. 2010. Enhanced and irreversible sorption of pesticide pyrimethanil by soil amended with biochars. *Journal of Environmental Sciences – Beijing* 22: 615-620.
- Yuan, J. H, Xu R. K. 2011. Progress of the research on the properties of biochars and their influence on soil environmental functions. *Ecol. Environ. Sci.* 20:779-785.
- Zhang, H., R. Voroney, G. Price. 2015. Effects of temperature and processing conditions on biochar chemical properties and their influence on soil C and N transformations. *Soil Biol. Biochem.* 83: 19–28.

- Zhang, H.; Lin, K.; Wang, H.; Gan J. 2010. Effect of Pinus radiate derived biochars on soil sorption and desorption of phenanthrene. Environ. Pollut. 158: 2821-2825.
- Zhang, X, W. Hailong, He. L, Lu. K, Sarmah. A, Li. J, Bolan S. N, P. Jianchuan and H.Huang. 2013. Using biochar for remediation of soils contaminated with heavy metals and organic pollutants. Environ. Sci. Pollut. Res. 20:8472-8483.
- Zheng, R. L., Cai, C., Liang, J. H., Huang, Q., Chen, Z., Huang, Y. Z., Arp, H. P. H, and Sun, G. X. 2012. The effects of biochars from rice residue on the formation of iron plaque and the accumulation of Cd, Zn, Pb, As in rice (*Oryza sativa* L.) seedlings. Chemosphere. 89: 856-863.
- Zhou J B, Deng C J, Chen J L, Zhang Q S. 2008. Remediation effects of cotton stalk carbon on cadmium (Cd) contaminated soil. Ecol. Environ 17:1857-1860.
- Zhu, L., N. Hu, M. Yang, X. Zhan, Z. Zhang. 2014. Effects of different tillage and straw return on soil organic carbon in a rice-wheat rotation system.9 (2).
- Zimmerman, A.R., 2010. Abiotic and microbial oxidation of laboratory produced black carbon (biochar). Environmental science & technology 44: 1295-1301.

Rabail Zulekha (MS Soil Science)

Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad 3804, Pakistan

Email: rabail.zulekha002@gmail.com

Riaz Bibi (PhD Candidate)

Gwangju Institute of Science and Technology, Gwangju, South Korea

Email: riazbibaloch@gmail.com

Zulfiqar Ahmad (Assistant Professor-Research)

Key Laboratory for Algal Biology, Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan 430072, China

Email: zulfiqar@whu.edu.cn

Azhar Hussain (Assistant Professor-TTS)

Department of Soil Science, University College of Agriculture & Environmental Sciences, The Islamia University of Bahawalpur, 63100-Pakistan

Email: azharhaseen@gmail.com

Aslam Farooqi (Assistant Professor-TTS)

Department of Entomology, UCA & ES, The Islamia University of Bahawalpur, Bahawalpur, 63100, Pakistan

Email: aslam_farooqi1770@yahoo.com

Shaista Andleeb (Postdoc Fellow)

School of Resources and Environmental Engineering, Wuhan University of Technology, Wuhan, Hubei, 4300723, China

Email: shaistaandleeb444@gmail.com

Acknowledgments

Authors are thankful to Higher Education Commission (HEC), Islamabad, Pakistan for providing initial research support.

Dedication

We dedicate this humble effort to Professor Dr. Muhammad Arshad (*late*) in honor of his services.

Conflicts of Interest

There are no conflicts to declare.



© 2020 by the authors. TWASP, NY, USA. Author/authors are fully responsible for the text, figure, data in above pages. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>)

