Role of Biochar in Remediating Heavy Metals in Soil

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Chapter 14
Role of Biochar in Remediating Heavy Metals in Soil

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14.1 Introduction

Soil contamination in these days has become a worldwide problem of greatest magnitude. Despite comprehensive regulations, a huge increase in concentration of different elements and compounds from threshold level is observed in recent years [1]. The main reasons of contamination are natural processes like volcanic eruption and weathering of rocks, as well as anthropogenic activities such as smelting, mining, and overapplication of agrochemicals such as fertilizers and pesticide [1, 2]. Industrial and technological advancement increased pollutant intake into the environment. Heavy metals among these pollutants have great influence on fertility of agricultural soils [3]. Urbanization leads to promote the farmer's concern to use contaminated soil for the production of food crops [4]. Urban agricultural soils are contaminated because of waste water irrigation to increase the crop yield [5]. The wastewater used for irrigation is rich in toxic heavy metals which are major contributor to heavy metal pollution in the soils irrigated are amended with waste water and material [6, 7]. Heavy metals are toxic and stored in the environment because they cannot be broken down [8, 9]. Due to its persistent nature, heavy metals become part of the food chain and pose risks to human health and degrade soil quality. Generally soil chemistry and the chemical form of heavy metal are responsible for the existence of these metals in crops and plants. In soil, commonly the accessibility of all the metals surges due to acidic environments; the transfer factor of a particular

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element to the plants is also affected by the crop's type, such as Cd which is mainly considered a toxic element in soil and fertilizers because of its highest transfer factor for any crop [10]. The transfer of heavy metals from soil to plant is one of the basic mechanisms of human exposure to heavy metals through the food chain [11].

Here the overview of heavy metal pollution due to Pb, Cd, Cr, As Ni, Zn, and Cu is described. The concentration of these heavy metals above threshold level is lethal to human health. Some elements such as Cd and Pb, without microbial degradation above optimum level of concentration, put the plant growth at risk due to permanent adulteration in soil [12]. The continuous use of inorganic and biological fertilizers increased heavy metal pollution in soil [1]. It is very necessary to minimize the accessibility and phyto-availability of heavy metals to plants along with the restoration of contaminated soil for safe and healthy food production [13]. In situ remediation techniques have been emphasized in various studies about remediation of heavy metals. In recent years researchers much investigated the use of biochar as in situ soil amendment, and it was found to be effective in reducing the mobility of heavy metals in soils [9, 14]. Biochar method is known as Terra Preta de Indio, introduced from the dark soil of the Amazon basin and is of high utility. Biochar have high chemical stability in contaminated soils and is a C-rich material. A lot of researches are initiated to explore the distinctive use of biochar for continuing C sequestration [14]. Biochar which is porous and has high C content is prepared by pyrolysis of organic waste [14]. Carter et al. [15] defined biochar as follows: "it is a porous carbonaceous solid material manufactured by the process of thermo-chemical decomposition under little supply of oxygen appropriate for the benign and continuing storage of carbon." The International Biochar Initiative (IBI) described biochar as a charcoal which is used as a tool for agricultural and environmental management [9].

Biochar has proved to be a very effective tool for treatment of contaminated soils due to these reasons: it effectively adsorbs heavy metals and decreases bioavailability and toxin-induced stress to plants and microorganisms [13, 16]. Biochar compounds are a good source of organic material and mineral nutrients for microbes. It promotes the beneficial microbes that promote remediation and protect them from predators [17]. Biochar improves the soil fertility and plant growth by improving physical and chemical properties of soil and also increases the availability of useful nutrients [14]. In soils the use of biochar has proved to raise the stable C pool and minimize the increasing concentration of atmospheric CO_2 [18].

14.2 Biochar Production and Properties

14.2.1 Biomass Pyrolysis

Biochar is a fine-grained porous and carbonaceous solid material synthesized from waste biomass residues under limited oxygen condition and low to medium temperatures (450–650 °C) by the slow pyrolysis [19, 20]. Biochar is manufactured from renewable resources such as green waste and chicken manure [21]. With recent advancements, biochar can be produced by thermal decomposition of various kinds of organic feedstocks such as crop biomass, wood, agricultural residues (cereal straw, hazelnut and peanut shell, wheat straw, etc.), and industrial organic waste (sewage sludge and de-inking paper sludge [1]. Forest-remain biochar has low metal content, so the frequent use of this biochar has no negative effect on the agricultural soils [22].

14.2.2 Properties of Biochar

Biochar, a carbon-rich material, is now well known because of its agronomic benefits and ability to moderate climate change by carbon sequestration potential [23–25]. The biochar proved to have an effective role as a soil conditioner and fertilizer [26]. The properties of biochar include highly porous structure, high surface area, pH, cation exchange capacity (CEC), adsorptive capacity, carbon content, organic matter content, and high water-holding capacity. It reduces CO_2 emission, retains nutrients and, pesticide [3, 12, 26, 27], making it a perfect soil amendment to remediate heavy metals and to recover the fertility. Activation of biochar is very effective to improve the adsorption capacity of biochar. The nutrient retention and uptake by plants are enhanced due to activation of biochar as compared to non-activated biochar [28]. Therefore, steam activation is an exciting opportunity for prospective biochar applications because it revealed to almost double the constructive effects of biochars in all illustrations.

14.2.3 Factors Affecting Biomass Properties

The properties of biochar are dependent upon the type of feedstock and the production procedure. Depending upon these two main parameters, the composition of organic and inorganic contaminants in the biochar also changed, and application of this biochar may cause adulteration in the soil [22]. The source material of biochar may affect the carbon sequestration and conditioning capacity of soil [20]. Other factors such as the type of soil, the type of metal, the nature of biomass, the thermal decomposition conditions (pyrolysis), and the quantity of biochar used [13] may also have prominent effect on properties of biochars.

14.3 Heavy Metal-Contaminated Soils

Mostly the heavy metals such as Cu(II), Cd(II), and Ni(II) are found together in contaminated soils. Oxidation-reduction and acid-base properties of heavy metal ions affect the mobility of these heavy metals. Zn(II) and Pb(II) retain in soil, while Cr(II), Cu(II), and Cd(II) move through soil pore water. Cd(II) and Cu(II) form a complex with available natural organic material in the soil [26]. Mobility and bioavailability of Cu and Pb are a worldwide matter of concern especially in polluted soils of mining, shooting, and industrialized areas [29]. The frequent use of sewage, municipal composts, manure, mining wastes, and copper-containing fungicides is the main cause of Cu contamination in soil [30]. Higher concentration of Cu has detrimental effect on soil and reduces the population of bacteria, fungi, earthworms, and plant organic content in soil. It also disrupts the nutrient cycle and activity of enzymes such as arylsulfatase, phosphatase, dehydrogenase, and β-glucosidase [16]. Higher concentrations of Cu in fruits and vegetables cause gastrointestinal cancer [31]. In areas rich in Pb and Zn rocks, Cd is obtained from lithogenic sources. Recently, the increased level of Cd in contaminated soils is due to the frequent application of fertilizers and sewage sludge on agricultural soils.

However, plants have high tolerance level for Cd as compared to animals and humans due to this reason: Cd is only toxic to plants at significantly higher concentrations. Disease itai-itai caused by high ingestion of Cd may also cause cancer and damage the kidney [2]. Municipal waste incineration; coal combustion; Pb, Cu, or Zn smelter; electroplating; nickel–cadmium batteries; and pigment production are the major anthropogenic sources of Cd in the environment (World Health Organization, http://www.euro.who.int/en/home). Consequently, Cd content is increased due to the usage of phosphatic fertilizers and sewage sludge [32]. Smelting processes are the main cause of Zn production. Among other sources, cosmetics, galvanized products, television, coating of metals, rubber and tire industries, and Zn alloys are prominent. However, as compared to Cd, Zn is less toxic. The presence of Zn in soil is affected by pH, organic content, and structure and nature of parent material. Zn is a transition metal and is an essential micronutrient for many biological processes, but it is toxic at higher concentrations; Zn is the most abundant trace heavy metal existing in agroecosystems [33]. Zn is also entering in the environment from sources such as municipal waste treatment plants and burning of coal and waste.

Municipal waste treatment plants and burning of coal and waste are also sources of zinc. The bioavailability of zinc in alkaline soil increases due to its solubility. Zn(II) also has the mobility in acidic soils [34]. The adverse effects of Zn on plant physiology are widely reported [35]. The solubility and bioavailability of Pb increase in soil due to weather and oxidation processes which modify the metallic Pb in soil. After its bioavailability, Pb promptly adsorbed on the sediment and soil particles, and it also tends to accumulate in plants and animal bodies [29]. Arsenic (As)-contaminated soils deteriorate the water quality because it leaches down from the soil and contaminated water sources such as the rivers and canals. The process of oxidative phosphorylation and synthesis of ATP in cells is also disturbed from high concentration of arsenic [3].

Arsenic also has detrimental effect on the activity of microbial population, soil biota, and nutrient cycles [36]. Ni originated in the environment both from the natural and anthropogenic process. The weathering of rocks and human activities such as smelting, plating, and mining are the main sources of Ni contamination of soil. For agricultural soils, application of organic waste material such as sewage sludge and fertilizer application are the main causes of contamination [1]. Chromium exists in the contaminated soil as Cr(III) and Cr (VI) ions. Chromium oxidation states are responsible for toxicity toward plants and animals, such as Cr(III) which is an essential nutrient and has less solubility in acidic and alkaline soils, whereas Cr(VI) is highly soluble in acidic and alkaline soils considered as carcinogen. Cr(VI) has a harmful effect and disturbs the biological activity of the soil. The soil properties play the main role in the availability of heavy metals to plants for uptake [10, 37]. In soil, the various enzymatic activities of bacteria are disrupted due to modification of soil environment by chromium (Cr).

14.3.1 Heavy Metal Remediation by Biochar

Namgay et al. [38] documented a decrease in the accessibility of heavy metals after the contaminated soil was amended with biochar, due to which plant absorption of the heavy metals is reduced. Unlike many other biological amendments, biochar having the ability to increase soil pH [39] might have improved sorption of these metals, consequently decreasing their bioavailability for plant uptake.

14.3.2 Heavy Metals Found in Soil

Generally Cu, Zn, As, Cr, Co, Ni, Sb, Hg, Th, Pb, Se, Si, and Cd are heavy metals that originate in soil which may be extremely harmful to human and plant life by contamination of soil and water. Heavy metals do not have the ability to biodegrade, so they can persist in polluted soils for a longer time [40]. There is a prerequisite to remove these metals, and the best convenient way is by environmental friendly techniques, i.e., biochar. From a long period, biochar is being applied to overcome the problem of heavy metal contamination and to improve soil fertility. Depending on the soil type, diverse types of biochar are used for different types of heavy metals, as demonstrated in Table 14.1.

Biochar has high pH and organic carbon content; higher concentrations of phosphorous, calcium, and magnesium; and low particular surface area than activated carbon [41]. That's why the addition of biochar brought a notable proliferation in soil cation exchange capability [42]. Biochar is considerably more active in restraining soil Pb than AC [41]. Biochar has excellent adsorption capacity due to its asymmetrical plates and porous structure (Fig. 14.1) [42].

The biochar produced from different sources showed similar results [43]. The maximum falloff of transferable Pb was achieved at 10 % application rate of biochars with steady reduction of 68 and 30 % for sugar cane biogases and orange peel, respectively [3]. Biochar is prosperous in nutrients, i.e., nitrogen, calcium, magnesium, and phosphorous in addition to carbon. Concentration of carbon and nitrogen are reduced with the increase in temperature, although Mg, Ca, and P were augmented by rise in temperature [43]. 93 % of lead was absorbed by biochar at 100,

Table 14.1 Heavy metal removal by different types of biochar

Contaminants	Biochar type	Matrix	Effects	References
As and Cu	Hardwood	Soil	Mobilization due to enhanced pH and DOC	Beesley et al. [67]
As, Cr, Cd, Cu, Ni, Pb, and Zn	Sewage sludge (500–550 °C)	Soil	Immobilization of As, Cr, Ni, and Pb due to rise in soil pH. Mobilization of Cu, Zn, and Cd due to highly available concentrations in biochar	Khan et al. [68]
Cd and Zn	Hardwood	Soil	Immobilization due to enhanced pH	Beesley et al. [67]
Cd, Cu, and Pb	Chicken manure and green waste (550 °C)	Soil	Immobilization due to partitioning of metals from exchangeable phase to less bioavailable organic-bond fraction	Park et al. [20]
Cu	Broiler litter (700 °C)	Soil	Cation exchange; electrostatic interaction; sorption on mineral ash content; complexation by surface functional groups	Uchimiya et al. [69]
Cu and Pb	Oakwood	Soil	Complexation with phosphorus and organic matter	Karami et al. [70]
Pb	Dairy manure (450 °C)	Soil	Immobilization by hydroxypyromorphite formation	Cao et al. [41]
Pb	Oakwood (400 °C)	Soil	Immobilization by rise in soil pH and adsorption on biochar	Ahmad et al. [29]
Pb	Rice straw	Soil	Nonelectrostatic adsorption	Jiang et al. [42]
Pb, Cu and Zn	Broiler litter (300 and 600 °C)	Soil	Stabilization of Pd and Cu	Uchimiya et al. [48]
Ni, Cu, Pb, and Cd	Cottonseed hulls (200–800 °C)	Soil	Surface functional groups of biochar-controlled metal sequestration	Uchimiya et al. [71]

while at 200 and 350, approximately the entire lead was removed from the soil solution [43]. The pH is the main parameter for disturbing adsorption and/or desorption of heavy metals in acidic soils. The amplified system pH by application of biochar increases the adsorption of Pb(II) in the soils. Biochar results in pH increase that flourishes the negative surface charges in the soil and enhanced the attraction for cations [44].pH rise is beneficial for heavy metal control in bulk soils. The increasing amount of biochar reduced the acid soluble Pb(II) and Cu(II) by 18.8–77.0 % and 19.7–100.0 %, respectively [42]. The uses of biochar, mussel shell, and cow bone reduced the lead phyto-availability by 55.50 %, 71.22 %, and 70.47 %, respectively, in army firing soil [45].

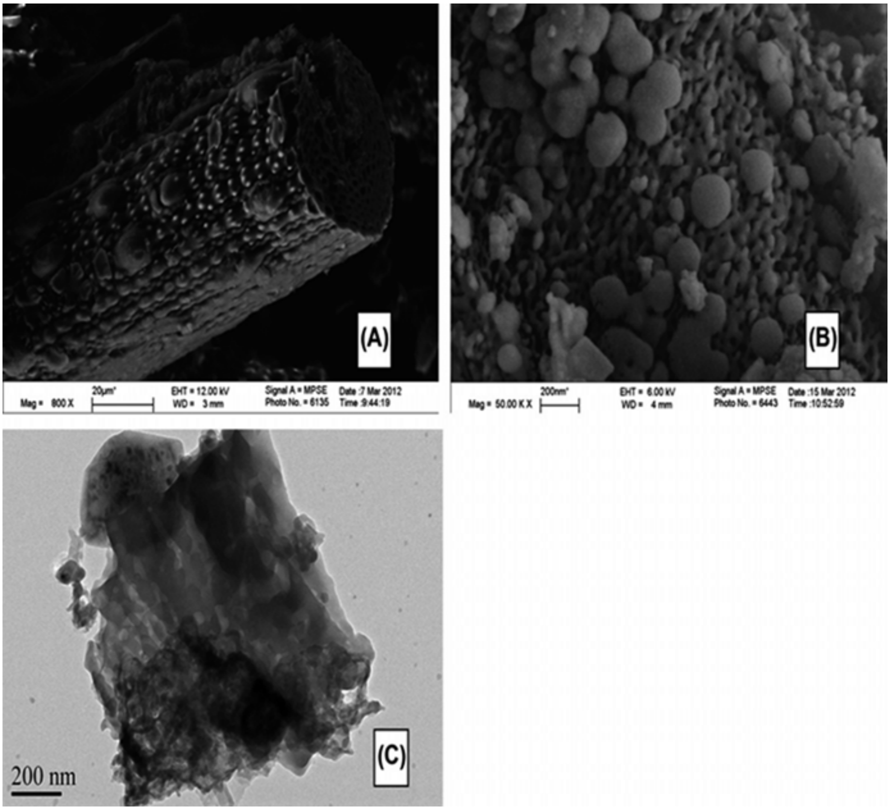

Fig. 14.1 SEM photographs of rice straw biochar at different magnifications: (**a**) ×800, (**b**) ×50,000, and (**c**) TEM photograph of the biochar

When the application rate of biochar produced from cow manure increased, the nutrient uptake, maize production, and photochemical properties of a dry land sandy soil considerably improved [46]. Sewage sludge-derived biochar successfully eradicates Pb^{2+} from acidic soil at early pH 5, 4, 3, and 2with the capabilities of 30.88, 24.80, 20.11, and 16.11 mg g^{-1}, respectively [47]. Biochar with phosphorus-rich manure serves as a fertilizer and is also used to remove heavy metal, specifically lead [48]. Historically, phosphorus in the biochar encouraged modification of less constant $PbCO_3$ to more stable $Pb_5(PO_4)_3OH$, liable for soil Pb restriction [41]. The application of biochar produced from cotton sticks put a positive impact on the cadmium-stressed soils by increasing the plant growth. It is due to the unique capacity of biochar that the metal ion is separated and the cadmium ion movement to the aerial tissue of plants is controlled [49].

The biochar synthesized from swine manure at 450 °C could contribute as a possible amendment for the control of heavy metals (Cd^{2+}) in sandy soil [9]. Biochar produced from green waste restrained lead, copper, and cadmium by 36.8 %, 22.9 %, and 30.3 %, respectively, for pointed soil and by 72.9, 0.901, and 42.7 % for naturally polluted soils [20]. Bamboo-derived biochar can adsorb nickel, chromium, copper, and mercury, from both water and soils, and cadmium from polluted soils [40].

Table 14.2 shows the effect of biochar application on the mobility of heavy metals in soils.

In basic soils, carbonaceous tools, irrespective of biomass and pyrolysis, improved the Cu(II) restriction than Ni(II) [26] while the Cu(II) adsorption amplified with pH rise (3.5–6.0). Cu(II) has an adsorption capability in the following order: canola straw char < soybean straw char < peanut straw char [50]. Organic segments of biochars and natural organic matter can stimulate Cu(II) extraction by basic soil because of more carboxyl contents [26]. The unsaturated biochar detached about 70 % of Cr(III) at equilibrium time, although only 30 % of As(V) in batch kinetic trials, suggesting that biochar is highly effective in eliminating cations than anions [51]. Biochar derived from chicken manure is more active in controlling metals as well as plant growth than biochar derived from green waste. So, biochar derived from chicken manure can be used to improve phyto-stabilization of metal tainted soils [20].

Jiang et al. [42] explored that biochar derived from rice straw influences the bioavailability and mobility of Pb(II), Cu(II), and Cd(II) in an Ultisol. When the amendment dosage of biochar increased, the acid removable Pb(II) and Cu(II) reduced by 18.8e77.0 % and 19.7e100 %, respectively. With the addition of 5 mmol kg^{-1} of these heavy metals, for treatments with 3 and 5 % biochar, the reducible Pb(II) was 2.0 and 3.0 times greater than the samples deprived of biochar. Pore structure of the biochars produced from crop straws (i.e., rice, corn, wheat, and cotton) is more developed as compared to wood char because wood char has greater lignin content. Biochars with

Table 14.2 Effect of biochar application on the mobility of heavy metals in soils

Feedstock	Production temperature (°C)	Contaminants	Effects	References
Bamboo	Not available	Cd	Combined effect of electrokinetics, removal of extractable Cd by 76.9 % within 12 days	Ma et al. [72]
Hardwood	450	As, Cu, Cd, and Zn	Reduction in Cd in soil pore water by tenfolds; Zn concentrations reduced 300- and 45-folds, respectively, in column leaching test	Beesley et al. [67]; Beesley and Marmiroli [73]
Hardwood	450	As, Cd, Cu, Pb, and Zn	Biochar surface mulch enhanced As and Cu mobility in the soil profile; little effect on Pb and Cd	Beesley and Dickinson [74]
Wood	200 and 400	Cd and Zn	Reduction in Cd and Zn leaching loss by >90 %	Debela et al. [75]

lower lignin content have larger surface areas and more developed pore volumes. In case of Cd the order of corn straw > cotton straw > wheat straw > rice straw > poplar shaving is for the sorption capacity of biochar that was not stringently reliable to the surface area of biochars [52]. Uchimiya et al. [53] reported that a biochar adsorbs Cd, Cu, Pb, and Ni and perceived that the tendency of the elimination order was Ni < Cd < Cu < Pb. The affinity for metal immobilization upsurges in the following order: Pb(II) > Cu(II) > Zn(II) > Cd(II) [26].

Table 14.3 shows the effect of biochar application on the bioavailability of heavy metals in soils.

Table 14.3 Effect of biochar application on the bioavailability of heavy metals in soils

Feedstock	Production temperature (°C)	Contaminant	Effects	References
Cotton stacks	450	Cd	Reduction of the bioavailability of Cd in soil by adsorption or Co precipitation	Zhou et al. [76]
Hardwood-derived biochar	450	As	Significant reduction of As in the foliage of *Miscanthus*	Hartley et al. [77]
Eucalyptus	550	As, Cd, Cu, Pb, and Zn	Decrease in As, Cd, Cu, and Pb in maize shoots	Namgay et al. [38]
Orchard prune residue	500	Cd, Cr, Cu, Ni, Pb, and Zn	Significant 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. [78]
Chicken manure and green waste	550	Cd, Cu, and Pb	Significant reduction of Cd, Cu, and Pb accumulation by Indian mustard	Park et al. [20]
Chicken manure	550	Cr	Enhanced soil Cr(VI) reduction to Cr(III)	Choppala et al. [79]
Sewage sludge	500	Cu, Ni, Zn, Cd, Pb	Significant reduction in plant availability of the metals studied	Méndez et al. [80]
Rice straw	Not clear	Cd, Cu, and Pb	Significant reduction in concentrations of free Cu, Pb, and Cd in contaminated soils	Jiang et al. [42]
			Identification of functional groups on biochar with high adsorption affinity to Cu	
Quail litter	500	Cd	Reduction of the concentration of Cd in physic nut; greater reduction with the higher application rates	Suppadit et al. [81]
Oakwood	400	Pb	Bioavailability reduction by 75.8 %; bioaccessibility reduction by 12.5 %	Ahmad et al. [29]

14.4 Effects of Biochar on Soil

The increasing population of human and their activities put huge pressure on agriculture land to fulfill need of food. This overburden on cultivated land raised the problems of soil erosion and degradation and depletion of organic matter and vital nutrients from the soil. To overcome these problems, biochar can be used as an effective tool [54]. Biochar can be utilized to get agricultural, environmental, and economic benefits although the nature of these benefits can vary by type of biochar and nature of soil [55].

14.4.1 Agricultural Benefits

Application of biochar in soil results in the following positive impacts on the soil of agriculture lands.

14.4.1.1 Soil Fertility

The extreme use of fertilizers exacerbates the leaching of macronutrients from the agriculture lands leading to decrease in soil fertility, amplification of acidity, and increased requirements of fertilizers that resulted in ultimate low crop yield [56]. Biochar fulfills the nutrient requirement of the soil and improves the soil fertility and productivity that resulted in optimum yield of crops [57].

14.4.1.2 Crop Productivity

Biochar offers large surface area for soil microbes resulting in increase in microbial growth. It improves the degradation of organic matter and improves retention time of microbes in soil and increases availability of nutrients which are favorable for soil growth for better crop production [27, 49, 54]. The productivity of soil also increases due to the addition of biochar in soil because it increases the availability of C compound and minimizes the requirement of artificial fertilizers [58].

14.4.1.3 Water Holding Capacity

Biochar enhances the water-holding capacity of soil by improving the soil quality in terms of physical, biological, and chemical fertility and better plant root density [59].

14.4.1.4 Cation Exchange Capacity

The application of biochar causes the stabilization of heavy metal, increases CEC, and increases the availability of higher mineral essential for plant growth [48, 60].

14.4.1.5 pH of soil

The specific pH properties of biochar make the soil acidic for evaporation of metal ion in soil. The soils with low pH and CEC will also have the low adsorption caption for metals [61].

14.4.1.6 Uptake of Heavy Metals

The addition of biochar reduces the heavy metal uptake by plant roots and minimizes the chance of low productivity due to toxicity in plant body [59].

14.4.1.7 Waste Reduction

The production of biochar is also an innovative technique to make beneficial reuse of waste and to minimize the waste volume [41].

14.4.1.8 Moisture Holding Capacity

The moisture holding capacity is improved due to application of biochar due to retention of pollution for shorter or longer time duration [62].

14.4.1.9 Adsorbent Capacity

Biochar has high adsorbent capacity for adsorption of heavy metals and minerals in soil. Due to its high competency to adsorb organic contaminants for purification of soil from contaminants, it improves the soil fertility [63, 64].

14.4.1.10 Soil Respiration Rate

The respiration of soil improves by decomposition of biochar with the help of microbes (bacterias) resulting in C production which is used by microbes for microbial activity in soil [1].

14.4.1.11 Residing Capacity of Soil-Living Organisms

Biochar also improves the resistance capacity of living organisms residing in soil, i.e., earthworms (nematodes), insects, fungus, etc. [58].

14.4.1.12 Nutrient Availability

High concentration of ash in biochar increases the availability of nutrients which satisfies the need of soil for nutrients. In case of low ash concentration in biochar, compost or manure can be added to maintain the ratio of nutrients [65].

14.4.1.13 Rate of Germination

The rate of seed germination increased due to direct interaction of biochar with soil [58].

14.4.2 Environmental Benefits

Interaction of soil with biochar results in subsequent effects on environment:

14.4.2.1 Carbon Sequestration

Biochar has great resistance for biotic and biotic degradation in soil which emphasizes its importance in carbon cycle as carbon sink [66]. Carbon sequestration resulting in reduction of CO_2 in the atmosphere is due to the long-term availability of biochar in soil. It also has the ability to minimize the effect of climate change, decrease in GHG (greenhouse gas), and NO_x emissions by causing decline in C emission as output from burning fossil fuels. Methane and nitrous oxide produced from carbon cycle and nitrification/denitrification process, respectively, can be reduced by application of biochar, and thus biochar can play an important role to solve issues of global warming [54, 56, 57, 62].

14.4.3 Economic Benefits

Application of biochar is also beneficial for the economy.

14.4.3.1 Economically Beneficial

Biochar is desirable nowadays because of its low energy demand, ease of use, low cost, and no pretreatment for use in soil.

14.4.3.2 Environment Friendly

The eco-friendly nature of biochar made it desirable, and nowadays it is being widely used in various applications because it (1) can be reuseable, (2) can recycle the organic waste, and (3) can reduce waste quantity [64].

14.5 Conclusion

Global industrialization leads pollutants to the environment. Among these pollutants, heavy metals have the profound effect on fertility of soils. Biochar amendments remediate heavy metal toxicity in agricultural soils through different processes. Biochar is an effective tool for contaminated soil due to these different processes: (1) adsorption of heavy metals; (2) highly porous structure and high surface area; (3) CEC; (4) reduced CO2 emission; (5) high water-holding capacity; (6) retention of pesticides, PAHs, and PSBs; (7) reduction of bioavailability and toxin-induced stress to microorganisms and plants; (8) C-rich material having high chemical stability in the contaminated soils and mineral nutrients for microbes; (9) reduction of the mobility in soil; (10) protection of microbes from predators and introduction of beneficial microbes that promote remediation; and (11) improvement of soil fertility and plant growth by improving physical and biological properties of soil by provision and maintenance of nutrients.

However, these processes vary with biochar type, nature of soil, type of plants, type of metal toxicity, conditions of thermal decomposition (pyrolysis), and the quantity of biochar used. Therefore, we should use biochar according to soil contamination. However, the various facts of opinions founded on comprehensive point of views should not be snubbed. Variant consequences recommend that recent biochar application to soil is not a standard example, as an alternative extensive concern of the properties related to each specific biochar material and how those properties could cure a particular soil scarcity are mandatory [55]. Biochar use in soil has been suggested to increase the stable C pool and limit the growing concentration of atmospheric CO_2. In conclusion much more investigations are required to check the long-term environmental and economic feasibility of biochar application to remediate heavy metal-contaminated soils.

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