Chapter 10
Utilization of Agricultural Waste as Biochar for Soil Health

A. G. Rajalakshmi

Abstract The utilization of agricultural wastes are considered to be the important step in environmental protection, energy structure and agricultural development. The agricultural straw disposition of agricultural wastes not only results in environmental pollution, but also waste a lot of valuable biomass resources. Biochar the viable organic amendment product derived from organic sources and store carbon on a long term basis in the terrestrial ecosystem and also capable of reducing greenhouse gases (GHG) emission from soil to the atmosphere to combat climate change and sustain the soil health with sustainable crop production. The role of biochar in developing a sustainable agriculture production system is immense and so is its potential in mitigating climate change, which stands much beyond its uses in agriculture. The addition of biochar to soils resulted, on average, in increased above ground productivity, crop yield, soil microbial biomass, rhizobia nodulation, plant K tissue concentration, soil phosphorus (P), soil potassium (K), total soil nitrogen (N), and total soil carbon (C). The effects of biochar on multiple ecosystem functions and the central tendencies suggest that biochar holds promise in being a win-win-win solution to energy, carbon storage, and ecosystem function. However, biochar's impacts on a fourth component, the downstream non target environments, remain unknown and present a critical research gap.

Keywords Utilization · Biochar · Carbon sequestration · Soil health

10.1 Introduction

The global food system is estimated to contribute minimum one third anthropogenic emissions (Scialabba and Muller-Lindenlauf 2010). The rice and wheat system (RWS) is one of the widely practiced cropping systems in northern India. About 90–95% of the rice area is used under intensive rice wheat system (RWS) in Punjab (Gadde et al. 2009). Burning of straw emits emission of trace gases like CO_2, CH_4,

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CO, N_2O, NOX, SO_2 and large amount of particulates which cause adverse impacts on human health. It is estimated that India annually emits 144,719 Mg of total particulate matter from open field burning of rice straw (Gadde et al. 2009).

Agriculture contributes between 10% and 25% of annual GHGs, both directly and indirectly, through land-use changes, land management, and production practices (Scialabba and Muller-Lindenlauf 2010). Agriculture is an important contributor to climate change, accounting directly for 10–12% of anthropogenic greenhouse gas (GHG) by land use change emissions (Hosonuma et al. 2012; IPCC 2014; Tubiello 2015). Agriculture influences global warming due to related direct and indirect GHG emissions from C and N dynamics. GHG emissions from soils a key topic in global change issues, climate research, and for agricultural and forestry management. SOC sequestration through improved crop and grassland management offers the possibility to sequester significant amounts of carbon in the soil, improving soil quality and productivity, and subsequently food security (Smith 2016).

Improved agriculture practices can reduce the amount of GHGs entering the atmosphere (Scialabba and Muller-Lindenlauf 2010; Smith et al. 2007), and carbon sequestration is considered a partial solution to short- and medium-term removal of atmospheric carbon (Hutchinson et al. 2007; Lal 2010; Morgan et al. 2010). Mitigation and adaptation differ in at least three ways including: (1) temporal and spatial scales at which the options are effective; (2) methods by which costs and benefits can be inventoried, estimated, and compared; and (3) stakeholders and governance drivers involved in their implementation (Klein et al. 2005; Tiwari et al. 2019a, b; Singh et al. 2019; Kour et al. 2019). Climate change adaptation for agriculture involves building resistance (the ability to resist the impact of a disturbance) and resilience (the ability to recover from disturbance) within agro-ecosystems, communities, and governance operations to prepare for climatic change and its impacts (Holt-Giménez 2002).

The Indian Ministry of New and Renewable Energy, estimated at ~500 million metric tons of biomass per year. The biomass residues used as animal feed, home thatching, and for domestic and industrial fuel, a large portion of unused crop residues are burned in the fields to clear the left-over straw and stubble after harvest, causing serious air pollution and producing CO_2 contributing to global warming. It also causes a huge loss of carbon feedstock which can be used to improve soil fertility (Fig. 10.1).

10.2 Agricultural Waste Management

Agricultural wastes production resulted in increased quantities of livestock waste, agricultural crop residues and agro-industrial by-products. It is estimated that about 998 million tonnes of agricultural waste is produced yearly (Agamuthu 2009) AWMS consist of six basic functions includes production, collection, storage, treatment, transfer, and utilization. Streets et al. (2003) reveal that 16% of total crop residues were burnt about 116 million tons of crop residues were burnt in India in

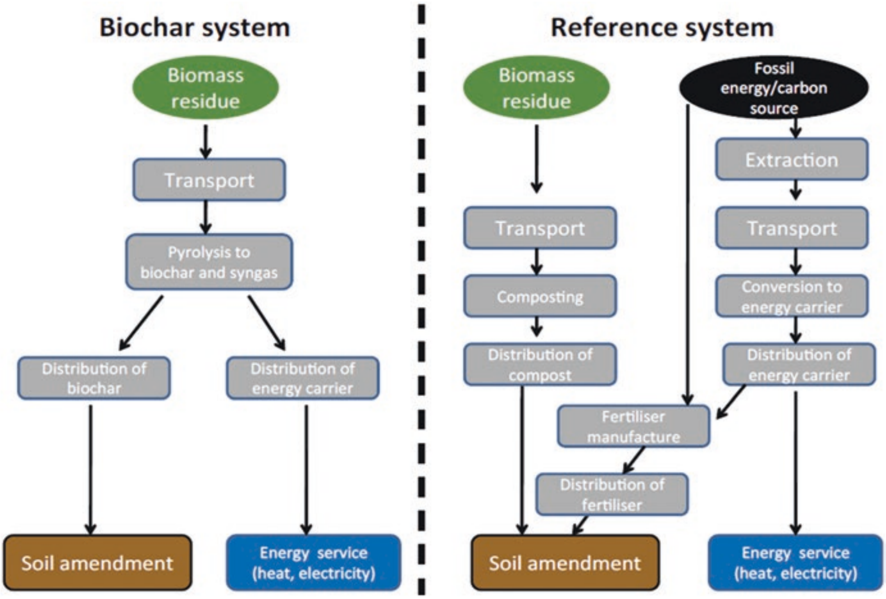

Fig. 10.1 Biochar as renewable energy source

2001, but with a strong regional variation (Venkataraman et al. 2006). The current availability of biomass in India (2010–2011) is estimated at about 500 million tons/year. Globally 78 ± 12 Gt C (this is equivalent to 29% of total CO2-C emission due to fossil fuel combustion of 270 ± 30 Gt.

Nguyen and Lehmann (2009) found that biochar formed during the conversion of undisturbed land to agricultural land by the burning of the natural vegetation, led to the formation of biochar and irrespective of its origin, the initial biochar content per unit soil mass decreased rapidly by 30% over a period of 30 years. Pyrolysis is incomplete combustion of biomass in oxygen limited condition, providing the slow cycling of organic carbon (Ameloot et al. 2013). The effective utilization of agricultural waste is a good option to convert these wastes in energy. Production of energy from biomass can provide farmers with new prospects and possibilities to diversify agricultural activities. Some of the crops may compete for land and other resources with traditional crops, while other crops may be grown on marginal lands or even ecologically degraded areas and thus have a positive effect on the environment.

Soil C sequestration implies increasing the concentration pools of SOC through land-use conversion and adoption of recommended management practices (RMPs) in agriculture. Application of manure and other organic amendments is another important SOC sequestration strategy (Anderson et al. 2011). Terrestrial ecosystems comprise a major C sink owing to the photosynthesis and storage of CO_2 in live and dead organic matter. Terrestrial C sequestration is often termed as a win-win strategy (Lal 2004) because of its numerous ancillary benefits. The quantity of carbon contained in soils is directly related to the diversity and health of soil life.

Biochar is part of the oldest C pool in soil (Pessenda et al. 2001) and deep-sea sediments (Masiello and Druffel 1998), and that black C may represent a significant global sink of C (Schmidt and Noack 2000)

10.3 Biochar a Safe Alternative Sources for Carbon Sequestration

Diminishing increased levels of CO_2 in the atmosphere is the use of pyrolysis to convert biomass into biochar, which stabilizes the carbon (C) that is then applied to soil. Biochar contains high concentrations of carbon that can be rather recalcitrant to decomposition, so it may stably sequester carbon (Glaser et al. 2002).

Organic carbon sequestered in soils is extracted from the atmosphere by photosynthesis and converted to complex molecules by bacteria and fungi in synergy with insects and animals. Soil C sequestration implies increasing the concentration pools of SOC through land-use conversion and adoption of recommended management practices (RMPs) in agriculture. Terrestrial ecosystems comprise a major C sink owing to the photosynthesis and storage of CO_2 in live and dead organic matter. The quantity of carbon contained in soils is directly related to the diversity and health of soil life. Formation of charcoal and use of biochar as a fertilizer is another option (Singh et al. 2017a, b, c, 2018; Tiwari et al. 2018; Fowles 2007) for carbon sequestration. Biochar is part of the oldest C pool in soil (Pessenda et al. 2001) and deep-sea sediments (Masiello and Druffel 1998), and that black C may represent a significant global sink of C (Schmidt and Noack 2000) (Fig. 1.2).

Biochar a new era with innovation and technological solution to reduce CO_2 emission and acts as a sequester almost 400 billion tonnes of carbon by 2100 and to lower atmospheric CO_2 concentrations by 37 parts per million (Tim Lenton 2009). Biochar needs two essential qualities to meet profitable agriculture: adoption of a carbon market and the market price for biochar must be low enough to make farmer friendly (Galinato et al. 2011). Apart from all the environmental stresses biochar exhibits a long mean residence times in soil, ranging from 1000 to 10,000 years, with 5000 years (Krull and Lyons 2009), this susceptible factor is mainly due to the complex chemical structure, aromatic nature, and graphitic C (Glaser et al. 2002). It is estimated that use of this method to “tie up” carbon has the potential to reduce current global carbon emissions by 10%.

10.4 Effect of Biochar on Soil Amendment

The char an energy source and as a soil amendment called biochar (Glaser et al. 2001) resist physical and microbial breakdown, allowing it to persist in soil due to the presence of crystalline morphology, the proportion of which may change with pyrolysis temperature (Cao and Harris 2010). The cations in the biochar after pyrolysis transformed into oxides, hydroxides, and carbonates (ash) acts as a liming agent when applied to soil. Application of biochar to soils contribute to carbon storage but at the same time act as fertilizers (Glaser et al. 2001; Marris 2006). It has been observed in several studies that biochar addition to soils improves soil fertility and thus increased crop yields on agricultural lands (Marris 2006; Chan et al. 2007). The possible improvements of soil's properties and fertility after biochar application (Fig. 1.3) due to the high surface area, amount of functional groups, and the content of liming. The well-developed pore structure enhances the capacity of water retention, 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.

10.5 Application of Biochar

The effect of biochar amendment on soil nutrient content, charcoal amendments have a positive effect on nutrient retention, particularly in highly weathered soils with low ion-retention capacities (Glaser et al. 2002). Biochar application elevates total C, organic C, total N, available P, and exchangeable cations like Ca, Mg, Na, and K increase, and Al decreases in soil (Chan et al. 2007; Major et al. 2010) the plant uptakes several of these nutrients after biochar application (Chan et al. 2007; Major et al. 2010) (Fig. 1.4).

Biochar is a low density material that reduces soil bulk density (Laird et al. 2010) and thereby increases water infiltration, root penetration, and soil aeration, increase soil aggregate stability (Glaser et al. 2002). Soil enriched with biochar improves soil fertility and to mitigate climate change by reducing emissions of greenhouse gases from cultivated soils (Yanai et al. 2007). Application of biochar in soil may provide a novel soil management practice because of its potential to improve soil fertility, enhance soil carbon, mitigate soil greenhouse gas emissions and enhance agricultural productivity (Fig. 10.2).

10.5.1 Biochar in Crop Production

Biochar improves plant growth and enhances crop yields, increasing food production and sustainability in areas with depleted soils, limited organic resources, insufficient water, access to agrochemical fertilizers. Beneficial effects of biochar with increased crop yield and improved soil quality (Glaser et al. 2002). Steiner et al. (2008) measured both higher soil N retention and an enhanced N cycling, biochar stimulation of crop yield mostly related to its higher stability in comparison to other organic amendments as well as the native soil organic matter (SOM) (Steiner et al. 2007). Biochar can capture high amounts of exchange cations (Lehmann et al.

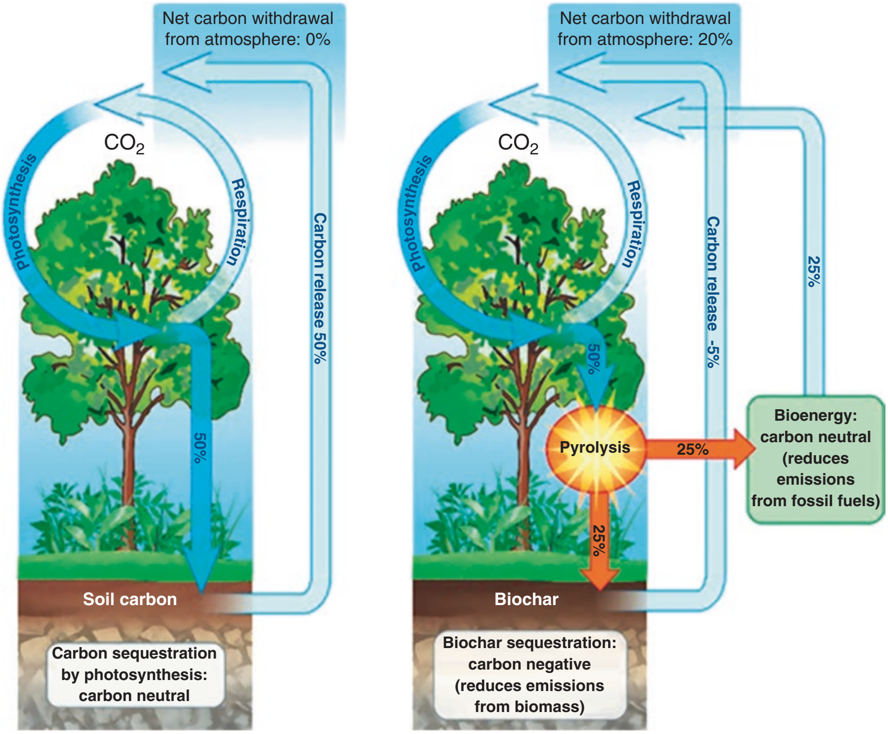

Fig. 10.2 Benefits of biochar application (Source Lehmann and Joseph 2009)

2003) because of its high porosity and surface/volume ratio and can improve plant nutrients uptake and P, Ca, K availability (Chan et al. 2007). In soils biochar is slowly oxidized, carboxylic groups are produced, cation exchange capacity and oxygen carbon ratio on the biochar surface increases (Brodowski et al. 2006), improving the capacity of biochar to retain nutrients in the long term Table 10.1.

Biochar application increases soil organic carbon levels (McHenry 2009) and improves soil structure (Glaser et al. 2002). Its application improves the soil's ability to retain moisture (Laird et al. 2010; Steiner et al. 2007), prevents nutrient leaching (Taghizadeh-Toosi et al. 2011; Spokas et al. 2011) and increases cation exchange capacity (Clough and Condron 2010; Yuan and Xu 2011). Application of biochar reduces aluminum toxicity (Van Zwieten et al. 2010) and bioavailability of heavy metals (Méndez et al. 2012), increases soil pH (Yuan and Xu 2011; Deal et al. 2012), supplies essential plant nutrients and decreases the need for chemical fertilizers (Bird et al. 2011). Biochar improves the biological condition of soils (Kwapinski et al. 2010), increases soil microbial biomass and supports beneficial organisms like earthworms. The conversion of biomass to biochar reduces greenhouse gas emissions (Wang et al. 2011) and helps in sequestering atmospheric carbon in to the soil (Bolan et al. 2012).

Table 10.1 Effect of biochar on the crop yields

Study	Results	References
Comparison of maize yields between disused charcoals production sites and adjacent fields Kotokosu watershed, Ghana	Grain yield 91% higher and biomass yield 44% on charcoal site than control	Oguntunde et al. (2004))
Soyabean on volcanic ash loam, Japan	0.5 mg ha^{-1} char increased yield 151%	Chidumayo (1994),
	5 mg ha^{-1} char decreased yield to 63%	
	15 mg ha^{-1} char decreased yield to 9%.	
Bauhinia trees on alfisol/ultisol	Charcoal increased biomass by 13% and height by 24%.	Kishimoto and Sugiura (1985)
Cowpea on xanthic ferrasal	67 mg ha^{-1} char increased biomass 150%	Glaser et al. (Glaser et al. 2002)
	135 mg ha^{-1} char increased biomass 200%.	
Pea, India	0.5 mg ha^{-1} char increased biomass 160%.	Iswaran et al. (1980)
Mung bean, India	0.5 mg ha^{-1} char increased biomass 122%.	Iswaran et al. (1980)

10.5.2 Impact of Biochar on Nitrogen Fixation

Nitrogen is a plant macronutrient essential to the survival of ecosystems. Yet, in most cases the amount of N available to plants is low (Robertson and Groffman 2007), which limits the gross primary productivity (GPP) of the site (Gundale et al. 2011).

Biochar is a promising fertilizer reduces N losses from the soil and alters the nitrogen (N) dynamics in soils (Robertson 2012). The anthropogenically induced global N cascade is resulting in enhanced fluxes of nitrous oxide (N_2O), ammonia (NH_3), and nitrate (NO_3) leaching as a consequence of the increasing intensification of agricultural systems (Galloway et al. 2008). Biocharcontain bioavailable N forms, its mineralization soil N and C pools on the soil in ecosystems. Biochar forms on immobilisation and mineralization determines the of relatively short duration or more long-term. Besides the release of N intrinsically embodied in the biochar (Wang et al. 2012; Schouten et al. 2012) there have been attempts to further enhance the delivery of N using biochar by adding nutrients to the biochar prior to soil incorporation.

Beneficial agricultural management tool, the most promising prospects for biochar, to date, are: (1) the reduction of NH3 volatilisation via adsorption processes (urine patches, animal housing filters, composting); (2) the development of slow release N fertilisers; and (3) the reduction of N_2O emissions using fresh biochar additions to soils. However, even these areas require further research since the use of biochar as a mitigation tool demands a deeper mechanistic understanding and at the same time an increase in our ability to predict net effects over time.

Microbial immobilization (Ippolito et al. 2012), biochar, especially when pyrolyzed at low temperatures, usually contains considerable amounts of labile carbon (Nelissen et al. 2012). This carbon can serve as a microbial substrate, resulting in microbial demand for inorganic N, which thereby immobilizes the N through biotic processes (Nelissen et al. 2012). Ammonia volatilization is another mechanism that accounts for the loss of fertilizer derived N.

Biochar a safe alternative reduce or eliminate the need for commercial fertilizers. Fertilizer in rainwater runoff can damage river systems and the surface application of commercial fertilizers can be eroded by wind and rainfall which may mix with water and leads to toxicity. Incorporation of biochar into soil, reducing carbon stocks could be replenished and long-term storage of carbon can be increased. According to a CSIRO report, biochar has the potential to remove 1 billion tons of carbon from the atmosphere per year. The interaction between biochar and other organic amendments in soil should now be the focus of future research. This is a simplistic low cost means of adding nutrients to soil and helping agriculture flourish. Environmental protection and human health will be the leading benefactors in large scale biochar production.

10.5.3 Biochar Interaction with Soil Rhizosphere

Agricultural intensification transfer carbon (C) to the atmosphere in the form of carbon dioxide (CO_2), thereby reducing ecosystem C pools. Agriculture contributes 10–12% of the total global anthropogenic greenhouse gas emissions. Diminishing increased levels of CO_2 in the atmosphere by pyrolysis to convert biomass into biochar, which stabilizes the carbon (C) that is then applied to soil. Biochar with high concentrations of carbon that can be rather recalcitrant to decomposition, it stably sequester carbon. The immediate beneficial effects of biochar additions for nutrient availability are largely due to higher potassium, phosphorus, and zinc availability, and to a lesser extent, calcium and copper. The presence of biochar in the soil can improve soil chemical (e.g. pH, CEC), and physical properties (e.g. soil water retention, hydraulic conductivity). Acting as a habitat and substrate for soil microorganisms, biochar added in the soil can increase microbial activities (Pietikäinen and Fritze 2000).

Biochar addition to soil increases in root colonization of AMF. Arbuscular mycorrhizal (AM) fungi are symbiotic soil organisms. AM fungi play role in vegetative succession of ecosystem, plant diversification and productivity, as well as restoration and re-establishment of degraded ecosystems. Arbuscular mycorrhizal fungi (AMF) increases plant nutrition. The increase in the availability of major plant nutrients due to application of biochar and mycorrizhae, the plants form mycorrhizal symbioses with specialized soil fungi (Fig. 1.5). The combination of biochar, mycorrhizal fungi approaches the goal of a viable soil environment for sustainable plant growth. It has often been observed that application of organic biochar amendments results in a higher level of C sequestration when compared to other management strategies including fertilizer application and conservation tillage. The opportunities for carbon sequestration and the reduction of greenhouse gas emissions have not been explored at all, but they are potentially significant (Fig. 10.3).

10.5.4 Influence of Biochar on Soil Biota

Biochar increase microbial biomass in soil across ecosystems, ranging from boreal forests (Wardle et al. 2008; Zackrisson et al. 1996) to Amazonian uplands (Liang et al. 2010; Steiner et al. 2007). The increase in microbial biomass may be caused by improved soil habitability or retention of microbes in the soil via adsorption to biochar (Thies and Rillig 2009). Biochar with organic fertilizers have been reported to significantly improve soil tilth, crop productivity, and the availability of nutrients to plants. Improved crop response as a result of biochar amendment can be attributed to its nutrient content including the neutralization of phytotoxic compounds in the soil, the promotion of mycorrhizal fungi, and the alteration of soil microbial populations and functions (Steiner et al. 2008). Biochar mediated microbial com-

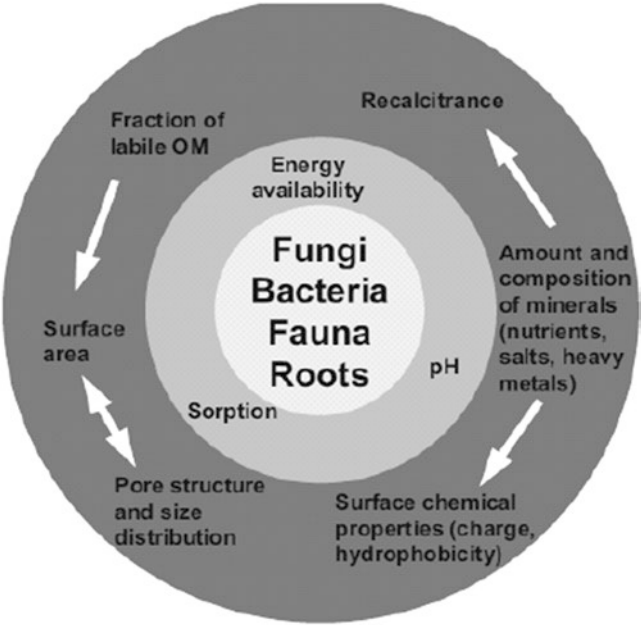

Fig. 10.3 Connection between primary biochar properties (outer circle), the soil process they may influence (intermediate circle) and the soil biota (inner circle), white arrows indicate the influence between biochar properties

munity compositional changes deserve further research, as these alterations can have essential implications for carbon sequestration and biogeochemical cycling. Biochar can promote a beneficial, self-sustaining soil biota, which also discourages plant-antagonistic organisms and pathogens. Soil biological activity, including the quantity, diversity, and activity level of soil microbes, affects soil productivity for crops. One study determined that biochar supported more microbial activity than pumice or activated-charcoal biochar, due in part to a higher water-holding capacity (Pietikäinen and Fritze 2000).

10.6 Outcome and Future Research Direction of Biochar

Soil is an essential component of the terrestrial ecosystem and has an important ecological function in biogeochemical cycling of resources needed for plant growth. An individual plant depends on soil for anchorage, water, oxygen and nutrients (Plaster 2009).

Contaminated soils and sediments are a significant worldwide environmental problem (The Norwegian Environment Agency 2017). Contaminated sites pose an environmental and human health hazard via ingestion and/or inhalation of contaminated dust or soil particles, consumption of crops produced on these sites as well as skin contact (Janus et al. 2015). Biochar as the sorbent for remediation of polluted soils is rapidly gaining popularity (Denyes et al. 2013). Sorbent amendment added to soils can alter the geochemistry of the soil, increase contaminant binding, reduce contaminant exposure risks to people and the environment as well as limit bioremediation (Cornelissen et al. 2005)

Biochar is a kind of insoluble, stable, highly aromatic and carbon-rich solid material produced by abandoned biomass under the condition of hypoxia and high temperature slow pyrolysis (usually The exchange adsorption of biochar surface is one of important reasons for the reduction of heavy metal activities. The bigger the number of cation exchange, the stronger the retention of heavy metals.

The larger surface area and higher surface energy are helpful for biocharstostrongly absorb the heavy metal pollutants and remove them from the soil (Fig. 1.7). The removal mechanism of heavy metals by biochars. Biochar is emerging tool to optimize the reduction of bioavailability of contaminants in the environment by making benefits to soil fertility and mitigating climate change (Sohi 2012). The inorganic contaminants in the environment (metals) derive from anthropogenic sources (Zhang et al. 2013).contains a fraction not carbonized, which could interact with soil contaminants and water the surface of the biochar could retain the contaminants (Uchimiya et al. 2010).

10.7 Conclusions

The biochar research has progressed considerably with important key findings on agronomic benefits, carbon sequestration, greenhouse gas emissions, soil fertility and health, removal of hazardous pollutants. Long-term field research focusing on an optimal combination of nutrient use, water use, carbon sequestration, avoided greenhouse gas emissions, and changes in soil quality, crop productivity and to promote the application of biochar as a soil amendment and also as a climate change abatement option, research, development and demonstration on biochar production and application is very vital. It is necessary to develop low-cost biochar kilns to make the technology affordable to small and marginal farmers. Efficient use of biomass by converting it as a useful source of soil amendment/nutrients is one way to manage soil health and fertility. The interaction between biochar and other organic amendments in soil should now be the focus of future research. This is a simplistic low cost means of adding nutrients to soil and helping agriculture flourish. Environmental protection and human health will be the leading benefactors in large scale biochar production.

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