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REVIEW ARTICLE

Impact of Biochar on Soil Health

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Abstract

Agricultural activities and soils emit greenhouse gases, and emissions occur in the conversion of land. Agricultural soils have lost a large portion of their antecedent soil organic carbon storage, becoming a source of atmospheric carbon-dioxide. Biochar is charcoal, optimized with characteristics deemed useful in agriculture, interest in biochar stems from its potential agronomic benefits and carbon sequestration ability. As a soil amendment, biochar can stabilize carbon belowground and potentially increase agricultural and forest productivity, which appear to be sensitive to the conditions prevailing during its formation. Proposed mechanisms evidence point to added environmental function in the mitigation of diffuse pollution and emissions of trace gases from soil; precluding the possibility of contaminants accumulating in soil from the incorporation of biochar. Biochar alters soil properties, encourages microbial activity and enhances sorption of inorganic and organic compounds. Research studies point to their ability to increase the plant available water in the soil which enables the plants to survive longer with water shortage, increase soil fertility and agricultural yields, improve soil structure, aeration and water penetration, and land reclamation. Biochar stability depends on the molar ratio of oxygen to carbon (O: C) in the resulting black carbon and appears to provide, at minimum, a 1000-year biochar half-life. The aim of this review is to provide a sound knowledge, and to recommend future research to systematically understand biochar-Ninteractions over the long term relating to biochar application to soils and the perspective areas yet to be explored.

Introduction

The major consequences of agricultural intensification are a transfer of 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. To meet the challenges of global climate change, greenhouse-gas emissions must be reduced. 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). Black carbon is found along a continuum of forms of aromatic carbon, from charred organic materials to charcoal, soot, and graphite (Schmidt and Noack, 2000).The immediate beneficial effects of bio-char additions for nutrient availability are largely due to higher potassium, phosphorus, and zinc availability, and to a lesser extent, calcium and copper (Lehmann et al., 2003a).

Biochar amendments alter soil physical properties; there also could be corresponding impacts on the reliability of flux chamber results from field plots due to differing chamber effects as a consequence of different soil physical properties (Venterea, 2008). It can increase soil aeration (Laird, 2008) and reduce soil emissions of N_2O, a greenhouse gas (Spokas et al., 2009; Singh et al., 2010). In current years, biochar has been shown as one promising mean of reducing the atmospheric CO_2 concentration because biochar slows the rate at which photosynthetically fixed carbon (C) is returned to the atmosphere (Lehmann, 2007 and Sohi et al.,2010).

In addition biochar canimprove agricultural productivity, particularly in low-fertility and degraded soils where it can be especially useful to the world's poorest farmers; it reduces the losses of nutrients and agricultural chemicals in run-off; it can improve the water-holding capacity of soils; and it is producible from biomass waste (Woolf et al.,2010). It has increased crop yield through various mechanisms including stimulation of beneficial soil microbes such as mycorrhizal fungi (Warnock et al., 2007), increase of soil base saturation (Glaser et al., 2002; Major et al.,2010a,b), increase in water holding capacity (Glaser et al., 2002 and Steiner et al., 2007), and retention of nutrients in the portion of the soil column containing roots, thus improving nutrient use efficiency (Chan et al., 2007; Steiner et al., 2008).

Agriculture and carbondioxide emission

India is an agrarian economy with a wide range of crops cultivated in different agro-ecological regions. Global agricultural production need to increase by 70 percent to meet the needs of an estimated world population of approximately 9.2 billion in 2050 (FAO, 2006a), but the environmental impact of changing land use to agriculture varies significantly under different management systems. According to (Bruinsma 2003) the demand in future results in need of increased crop intensity as less land becomes available for conversion to agriculture which has major implications for soil carbon stocks (Smith et al., 2010).

Terrestrial environments are important global carbon sinks (Prentice, et al., 2001; Schimel et al., 2000)and the size of this sink depends on the grasslands of the world (Pacala etal., 2001) therefore, the most feasible and cost effective approach to carbon sequestration is in restoring the massive sink in degraded soils.

Cropping system can influence CO_2 emission by affecting on the quality and quantity of residue returned to the soil (Curtin et al., 2000; Al-Kaisi and Yin, 2005; Amos et al., 2005). Increased above and below ground biomass production can increase the amount of residue returned to the soil (Sainju et al., 2005), thereby increasing CO_2 flux (Curtin et al., 2000; Al-Kaisi and Yin, 2005). The CO_2 emission from the soil to the atmosphere is the primary mechanism of C loss from the soil (Parkin and Kaspar, 2003).

Smith et al. (2000) conclude that there is considerable potential for carbon dioxide mitigation by agriculture. Changes in farming practices increases the organic carbon content of the soil, the reverse occurs: the soil captures more CO_2 than it emits, which means that CO_2 is removed from the atmosphere and stored in the soil. Land that has undergone few changes over the years, there is a balance between the carbon captured by the plants and the carbon returned to the atmosphere; the quantities of carbon stored in the soil do not change(Agriculture and Agri-Food Canada) Changes in the land management disrupts the carbon cycle.

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 2001, but with a strong regional variation (Gupta, 2010, 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 CO_2-C emission due to fossil fuel combustion of 270± 30 Gt (Lal et al., 2007).

Soil carbon plays a role in regulating climate, water supplies and biodiversity, and provides the ecosystem services that are essential to human well-being. On the other hand, maintenance of a threshold level of organic matter in the soil is crucial for maintaining physical, chemical and biological integrity of the soil and also for the soil to perform its agricultural production and environmental functions (Izaurralde et al., 2001; Srinivasarao et al., 2012, 2013) shown in Figure 1. Hence, conversion of organic waste to produce biochar using the pyrolysis process is one viable option that can enhance natural rates of carbon sequestration in the soil, reduce farm waste and improve the soil quality (Srinivasaraoet al., 2012, 2013).

Carbondioxide emission

Global carbon cycle estimated, 55 to 878 billion tons (GT) of carbon to the total atmospheric CO_2 (Kimble et al., 2002) from the soil. The soil organic carbon content is lost due to the conversion of natural state to agricultural land in the form of CO_2 (Vanden Bygaart et al., 2003). Depending on the physical factors, organisms in the soil food web decompose soil organic matter and make their nutrients available (Brussaard et al., 2007 and Taylor et al., 2009). Low nutrient content and accelerated mineralization of soil organic matter (SOM) are the two major constraints currently encountered in sustainable agriculture (Renner,2007).Soil carbon sink capacity increases most rapidly soon after a carbon-enhancing change in land management has been implemented (Johnson et al., 1995; Freibauer et al., 2004; Smith, 2004).

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. Ecosystems with fungal dominated soil communities may have higher C retention than soil communities dominated by bacterial pathways of decomposition due to differences in fungal mediated aggregate turnover (Six et al., 2006).

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., 1990).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 et al., 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. Formation of charcoal and use of biochar as a fertilizer is another option (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).

Biochar a safe alternative source for carbon sequestration

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).

The conversion of organic residues to biochar include the elimination of pathogens and the speciation of some heavy metal contaminants into forms with reduced levels of toxicity (Henry,2009). Biochar acts as alternative source as suggested by (Day et al., 2005) because it scrubs CO_2, SOx, and NOx from fossil-fuel power plant flue gases, and in the process, creating a slow release fertilizer which sequesters additional CO_2 , but the charcoal acts a soil conditioner stressed (Glaser et al.,2002). The physical and chemical properties of biochar are influenced by both the feedstock (Keech et al., 2005; Gundale and DeLuca, 2006) and the maximum temperature attained during pyrolysis (Gundale and DeLuca, 2006; Lehmann, 2007b). The porous nature of biochar, increase soil water-holding capacity, cation exchange capacity (CEC), surface sorption capacity (Glaser et al., 2002; Keech et al., 2005; Liang et al., 2008). Thus the high surface area serves as a surface for the sorption of hydrophobic organic compounds (Cornelissen et al.,2004;Bornermann et al., 2007).The physio-chemical properties of biochar made its interest in agriculture are as follows: 1) intention to improve soil functions; and 2) reduce emissions from biomass that would otherwise naturally degrade to GHG, by converting a portion biomass into a stable carbon fraction with higher sequestration value (International biochar Initiative, 2012) illustrated in Figure 2.Thus, biochar additions to mineral soil that increase soil pH are likely to favourably influence nitrification. Biochar may act as a habitat or safe site for soil microorganisms (Pietikäinen et al., 2000) involved in N, P or S transformations. Biochar certainly has the capacity to support the presence of adsorbed bacteria (Pietikäinen et al., 2000; Rivera-Utrilla et al., 2001) from which the organisms may influence soil processes and termed as nitrifier.

Environmental conditions and land use will impact the degradation rate of biochar in soil (Lehmann et al., 2009). Apart from all the environmental stresses biochar exhibits a long mean residence times in soil, ranging from 1,000 to 10,000 years, with 5,000 years (Skjemstad et al., 1998; Swift, 2001; Krull et al., 2003), this susceptible factor is mainly due to the complex chemical structure, aromatic nature, and graphitic C (Glaser et al., 1998).It is estimated that use of this method to “tie up” carbon has the potential to reduce current global carbon emissions by 10 percent (Woolf et al., 2010)

Effect of biochar on soil amendment

The char co-product acts as an energy source and as a soil amendment called ‘biochar’. Glaser et al. (2001) reported that “black carbon” (analogous to biochar) is very stable due to its polycyclic aromatic carbon structure and able to 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. Nguyen et al. (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. 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 improved soil fertility and thus increased crop yields on agricultural lands (Marris, 2006; Chan et al., 2007) as shown in Table 1.

Bio char is generated by heating organic material under conditions of limited or no oxygen (Lehmann, 2007b) thereby it increases soil quality and provides a way to fix atmospheric carbon dioxide (Lehmann, 2007b). 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). In addition to the effect of biochar amendment on soil nutrient content, charcoal amendments have been reported to 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, 2008; Major et al., 2010b; Van Zwieten et al., 2010) the plant uptakes several of these nutrients after biochar application (Chan et al., 2007; Major et al., 2010b). Major et al. (2010b) reported that nutrient uptake by plants was increased in biochar amended soil, with increase plant yield with greater availability of Ca and Mg in soil.

Biochar amendment in soil recycles most of the nutrients that are removed due to the harvest. Because of its high surface area and high surface charge density (Liang et al. 2006), biochar increases the ability of soils to retain nutrients and plant available water and reduces leaching of nutrients and agricultural chemicals (Laird et al., 2010b; Lehmann et al., 2003; Glaser at al., 2002). Biochar is a low density material that reduces soil bulk density (Laird et al. 2010b, Rogovska et al., 2010) and thereby increases water infiltration, root penetration, and soil aeration, increase soil aggregate stability (Glaser at al., 2002).

Brodowski et al. (2006) found the highest biochar contents are found within the micro-aggregate fraction of the soil, with the macro-aggregates containing lower amounts of biochar. Micro-aggregates play an integral role in reducing biochar decomposition by increasing the encapsulation of the organic fractions. Biochar can initiate increased aggregation when they are broken down to humic acid, aggregation may only play a role in reducing the decomposition rate of the biochar (De Cryze et al., 2006) with its own inherent recalcitrance playing the major role. Biochar addition to soils is a promising alternative to transfer more easily decomposable organic matter (Zech et al., 1990; Fearnside et al., 2001).

Influence of biochar on soil biota

Biochar amended soil was more suitable pH for the growth of microbes, especially for fungal hyphae, Wuddivira et al. (2009) due to its porosity, higher amounts of biochar in the treated soil increased the habitat for microbes to grow. Joseph et al. (2010) indicated that most of biochar has a high concentration of macro-pores that extends from the surface to the interior, and minerals and small organic particles might accumulate in these pores. Biochars having high surface areas (specific surface area; SSA) can be particularly challenging for pest control, adsorption strength is commonly much greater than that of low SSA biochars (Bornemann et al., 2007; Chen and Chen, 2009; Wang et al., 2010; Yang et al., 2010).

Incorporation of biochar into soils leads to initial degradation of biochar by chemical oxidation and microbial processes (Bruun et al., 2008; Nguyen et al., 2008; Smith et al., 2010). The processes that influence the energy flow and organic matter within the soil will impinge on bacterial and fungal-based energy channels, which impact at higher trophic levels (Atkinson et al., 2010 and Six et al., 2006).

The positive effect of biochar and earthworms in a greenhouse of soil types as reported (Noguera et al., 2010). Earthworms and biochar increase the availability of mineral nutrients suggesting that this mechanism has played an important role (Noguera et al., 2010). The main difference between earthworms and biochar effects on plant metabolism would be due to the fact that earthworms lead to the indirect release of plant growth factors but biochar also influences soil microbial communities (Pietikäinen and Fritze, 2000) and promotes the activity of micro-organisms (Atkinson et al., 2010).Soil biota is important to the functioning of soils and provides many essential ecosystem services. Liang et al. (2006) indicated that microbial populations could be even higher in soil rich in black carbon, thus the interaction between biochar as a soil amendment plays vital role in soil biota (van der Heijden et al.,2008).Furthermore, an increase of soil microbial biomass and a changed composition of soil microbial community were also observed after biochar amendments (Birk et al., 2009). The proliferation of microorganisms due to the biochar backbone as well as its pores, influenced by biological processes (Yoshizawa et al., 2005).

Impact of biochar on nitrogen fixation

Bio-char enhances biological N fixation (BNF) amendments in soil. This is mainly due to the: (1) the N availability in soil is lower due to the high C/N ratio of the bio-char and the resulting N immobilization (Glaser et al., 2002; Lehmann et al., 2003); (2) the availability of nutrients other than N and the pH are higher (Tryon 1948; Mikan and Abrams, 1995; Lehmann et al., 2003a; Oguntunde et al., 2004); and (3) the bio-char enhances mycorrhizal infection, (Saito and Marumoto 2002). The reason for the improved BNF are most likely a combination of factors related to nutrient availability in soil (Lehmann et al., 2003 a, b) and stimulation of plant-microbe interactions (Nishio and Okano, 1991; Saito and Marumoto, 2002), along with nitrogen nutrient levels also increases in biochar applied soil resulting in increased colonization of the host plant roots by arbuscular mycorrizae fungi(AMF) (Ishii and Kadoya, 1994). Biochar amended soils have greater crop biomass (Rondon et al., 2004; Major et al., 2010) and enhanced biological N-fixation in leguminous crops (Rondon et al., 2007). The fertilizer effect induced in plants may be explained by the retention of beneficial nutrients and pH neutralization.

The increase in the availability of major plant nutrients due to application of biochar occurs due the presence of small amounts of nutrients in biochar that would be available to soil biota (Yamato et al., 2006).The roots of nearly all land plants form mycorrhizal symbioses with specialized soil fungi. A simple term to define this is the buried alliance of plants and fungi and therefore this continues today to benefit plants. By this alliance with plants: 1) the fungi bring water, making the plants more drought-tolerant. 2) the fungi bring minerals essential to plant health to the roots 3) the fungi acts as antibiotic barriers to root pathogens 4) they increase the tolerance of plants to extremes in soil temperatures and pH. 5) increases the longevity. 6) tolerate stresses like transplant shock, soil compaction, soil toxins and heavy metals.

Biological nitrogen fixation in soils with biochar with large bio-char concentrations, available nitrate concentrations are usually low and available calcium, phosphorus, and micronutrient concentrations are high, which is ideal for maximum BNF (lehmann et al., 2003b).The biochar enhances mycorrhizal infection, as it is able to serve as a habitat for extra radical hyphae that sporulate in its micropores due to lower competition from saprophytes (Saito and Marumoto, 2002). Root infection by arbuscular mycorrhizae significantly increased by adding biochar as reported by (Nishio and Okano, 1991). The reason for the improved BNF when bio-char was added is most likely a combination of factors related to nutrient availability in soil(Lehmann et al.,2003a, b) and stimulation of plant-microbe interactions (Nishio and Okano,1991; Saito and Marumoto,2002).

Outcome of biochar in soil Remediation

Excavation of contaminated soil to landfill, considered environmentally disruptive and economically unfeasible (Salt et al., 1995;Mench et al.,2010).Modern remediation approaches increasingly assisted natural attenuation and phytostabilization often primed by the addition of soil amendments (Kumpiene et al. 2008; Clemente et al.,2005; Clemente et al.,2006; Hartley and Lepp,2008).The sorption of the chemical also is affected by soil properties including water, organic matter, clay, sand, and oxide contents, and soil pH (Koskinen and Clay, 1997; Laird and Koskinen, 2008).The soil organic matter (SOM) comprises of rubbery and glassy phases, where the latter comprises of black carbon geosorbents (Cornelissen et al., 2005; Rhodes et al.,2010a).Black carbon (BC) is the collective term thermally altered partly charred to highly condensed forms of organic carbon, which includes chars, charcoals, biochars, soots and graphite (Schmidt and Noack, 2000). BC acts as recalcitrant to influence mobility, extractability ,bioavailability of HOCs in soil (Rhodes et al.,2008a; Sundelin et al., 2004; Amonette et al.,2003) and also aids in stabilizing and restoring SOM in soils (Amonette et al., 2003). The soil remediation enhanced cation exchange capacity, binding of nutrients and prevention of subsequent nutrient run-off, reduced nitrogen leaching, improved soil water retention capacity, neutralizing soil acidity and providing conditions suitable for micro-organisms (Fowles,2007).

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 (Lehmann et al., 2003a). Carrots and beans grown on steep slopes had significantly improved yields by bio-char additions (Rondon et al., 2004). Improving the water holding ability of soil can greatly increase productivity in areas of low rainfall (Better Soils,1997).Roberts et al. (2010) highlighted the critical nature of the source material and bioenergy production in realising climate change benefits (Steinbeiss et al.,2009) also examined biochar residence in soil.

The polyaromatic structure of black carbon is extremely resistant to microbial attack, and extracellular enzymes are able to mineralize black carbon, with coal (Willmann and Fakoussa, 1997; Hofrichter et al., 1999). Higher microbial activity was reported in forest soils in the presence of charcoal by Zackrisson et al. (1996), due to the strong affinity of microbes to bio-char can (Stenstrom 1989; Huysman and Verstraete, 1993; Castellanos et al., 1997; Mills, 2003; Rivera-Utrilla et al., 2001). Bio-char has been widely applied in tree nurseries (Jaenicke, 1999) for propagation, due to its ability to adsorb inhibitory substances (Nhut et al., 2001). The particle size of the bio-char appears to play a minor role in its effect on soil fertility and crop production (Lehmann et al., 2003a), which simplifies the application of the technology.

The importance of earthworms in ecosystem functioning are considered as an essential part of the soil fauna in most soils, and their presence is regarded as a useful indicator of soil health (Edwards 2004). As a result earthworms have been widely used to give a measure of both organic (Bergknut et al., 2007; Gomez-Eyles et al., 2010) and inorganic (Spurgeon et al., 1994; Hobbelen et al., 2006) contaminant bioavailability. On top of giving a measure of soil toxicity it has also been suggested that earthworms could be inoculated into soils contaminated with organic pollutants (Contreras-Ramos et al., 2008) and metals (Wong et al., 2008) during remediation. However, a recent review suggests that earthworms generally increase the mobility and bioavailability of metals (Sizmurand Hodson, 2009). Also carbonaceous amendments may have an adverse effect on the habitat quality of the soils to the earthworms as found inprevious studies with aquatic oligochaetes (Jonkeret al., 2004). This suggests there is a need to examine the interactions between biochar and earthworms in soils contaminated with organic and inorganic contaminants.

Biochar can be used as a safe alternative reduce or eliminate the need for commercial fertilizers. Fertilizer in rainwater runoff can damage river systems (Westwood, 2003) and the surface application of commercial fertilizers can be eroded by wind and rainfall which may mix with water and leads to toxicity (Handrek, 1997). It also has the advantage over commercial fertilizers of potentially improving the water retention of the soil. Sorption controlled by properties of the chemical of interest including the water solubility, pH, dissociation constant (pKa), octanol/water partition coefficient, and other factors (Weber, 1995) and can be used to help describe the fate of an herbicide in the environment (Wauchope et al., 2002).Incorporation of biochar into soil, reducing carbon stocks could be replenished (Lehmann et al.,2006) and long-term storage of carbon can be increased (Kuzyakov et al.,2009 and McHenry, 2009). According to a CSIRO report, biochar has the potential to remove one billion tons of carbon from the atmosphere per year (Krull and Lyons, 2009). Yu et al.(2009) showed that mineralization of pesticides by plants was enhanced by the presence of biochar in soil, the microbial degradation of bioaccessible fractions of organic contaminants can be enhanced in the presence of biochar, whilst the volatilization is mitigated (Bushnaf et al.,2011)

A possible application of this review using biochar for remediation of contaminated soils, to prevent leaching into the water supply and harmful plant uptake as reported (Xinde and Harris, 2010). Biochar nutrient properties enhances plant growth and microbial activity to enhance biodegradation of bio accessible contaminants (Bushnaf et al., 2011; Yang et al.,2010; Kolb et al.,2009; Asai et al.,2009) it can be used in a systematic concept to promote phytoremediation, though it may be a long process can become rapid with different concentrations of biochar. Coconut charcoal was most efficient in promoting oil biodegradation. (Choet al., 1997).To exploit the benefits to soils, adding char to soil as finely divided particles increases the surface area and therefore the char'scapacity for contaminant adsorption (Nocentini et al., 2010).

Despite its potential to reduce greenhouse gas emissions, the widespread land application of biochar might also have a detrimental effect on global warming byincreasing the radiative forcing. The particle size of the biochar appears to play a minor role in its effect on soil fertility and crop production (Lehmann et al., 2003a), which simplifies the application of the technology. Lehmann et al. (2006) estimated that a total of 9.5 billion tons of carbon could potentially be stored in soils by the year 2100 using a wide variety of biochar application programs. Further studies are necessary to design the best possible soil amendments and to investigate the long-term behavior of these biochars in natural systems.

Biochar interaction with mycorrhizae

Biochar and mycorrhizae are two "hot" research challenging areas posed by global warming, alternative energy production and modern non-sustainable agricultural practices. Biochar and AMF in soil lead to an altered levels of nutrient availability that affects both plants and mycorrhizal fungi, modifies plant mycorrhizal fungi signaling, serves as a refuge from hyphal grazers and protected from soil predators (Akiyama et al., 2005) depicted Figure 4. Biochar soil amelioration in degraded landscapes has the potential to increase grassland plant production, enrich soil microbial populations, and stimulate arbuscular mycorrhizal persistence. Biochar addition to soil increases in root colonization of AMF (Ishii and Kadoya, 1994; Matsubara et al., 2002; Yamato et al., 2006) .These qualities in bio char serves as a good sorbent for organic and inorganic pollutants, it can be anticipated that chemical leaching to groundwater and run-off to surface waters will (Steiner et al., 2007; Steiner et al., 2008) be reduced, it can be a tool in the creation of sustainable food and fuel production in areas with severely depleted soils, scarce organic resources, and inadequate water and chemical fertilizer supplies. Biochar is hypothesized to reduce nutrient leaching in well drained soils. Nutrient retention in impoverished post-mine substrates should increase productivity by stimulating biotic-abiotic feedbacks.

Soil micro-organisms, especially arbuscular mycorrhizal fungi (AMF), in addition to ectomycorrhizal fungi (ECM) and ericoid mycorrhizal fungi (ERM), have well-recognized roles in terrestrial ecosystems (Zhu and Miller, 2003; Rillig, 2004; Read et al., 2004; Rillig and Mummey, 2006). Mycorrhizal fungi are frequently included in management; they are widely used as soil inoculum additives (Schwartz et al., 2006). ECM fungi and other rhizosphere microorganisms may benefit from changes in soil nutrient availability, which may alleviate growth limitations of fungi in nutrient poor soils (Treseder and Allen, 2002; DeLuca et al., 2006) and increase root colonization (Warnock et al., 2007).Among the microorganism living in the rhizosphere of plants, arbuscular mycorrhizal fungi have been found to be essential components of sustainable soil-plant systems (Bethlenfalvay and Linderman, 1992; Hooker and Black, 1995; Van der Heijden et al., 1998).

Mycorrhizal fungi are an important integral component of the plant-soil system, forming symbiotic associations with most land plants (Smith and Read, 2008; van der Heijden et al.,2008).Apart from the mineral supplement to AMF by biochar it also acts against biotic and abiotic stresses in nature (Sylvia et al., 1993; Al-Karaki and Al-Radded, 1997), as a result increase in the ability of AMF to assist their host in resisting infection by plant pathogens (Matsubara et al.,2002).Apart from AMF colonization finer parts of the mycelium and the hyphae(Klironomos and Kendrick, 1996),bacterial colonization is also protected from soil predators (Saito 1990;Pietikainen et al., 2000; Ezawa et al., 2002).The field studies indicate that AMF benefit native plant production in severely degraded areas (Johnson, 1998; Matias et al., 2009) in combination with biochar amendments can increase AMF percent root colonization among plants growing in acidic soils (Ezawa et al., 2002; Yamato et al., 2006). AMF and biochar can both improve crop performance; there is an increasing interest in understanding their potential synergisms.

Conclusion

The review emphasizes an overview into the current knowledge base surrounding the use of biochars for soil enhancement, remediation. There is an emerging level of enthusiasm surrounding biochar, and there is the potentiality of biochar to bolster regional economic development. The eventual oxidation and decomposition of biochar and organic matter in the soils can form the acidic materials that will partly neutralize soil alkalinity, which makes biochar a limiting agent of the soil salinization process. Soil amendments to restore severely disturbed landscapes in a reasonable timeframe. 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. The profitability of any biochar operation will depend mainly on its potential to attract revenue as a soil additive and C sink and will be affected by the type of biomass feedstock and that of production, which can, in turn, result in environmental and economic spillovers. 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.

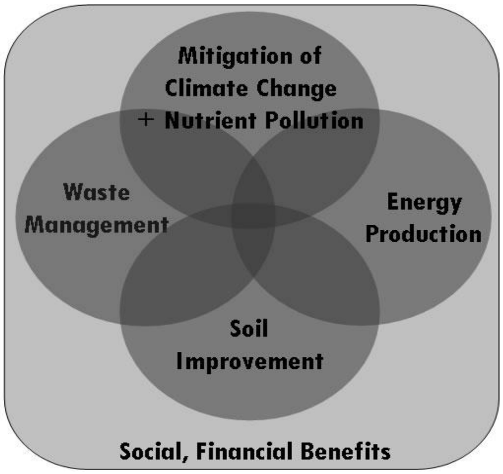

Figure 1: Biochar system components (Lehmann and Joseph 2009).

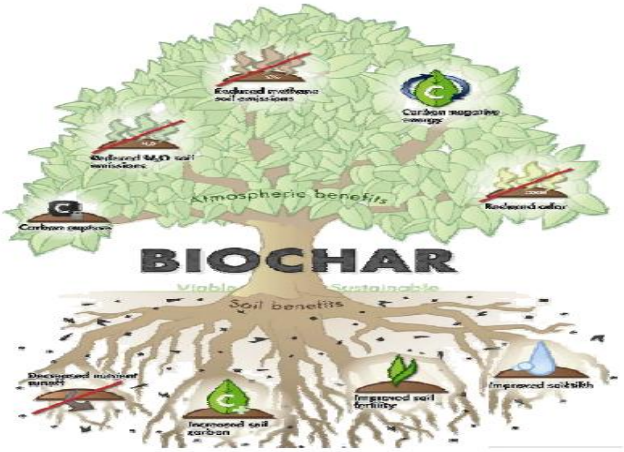

Figure 2: Multifold benefits of biochar (Kavin D.Brown)

Table 1: Studies of effect of biochar on the crop yield

Authors	Study	Results
Oguntude (2004)	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
Yamato (2006)	Maize, cowpea and peanut trial in area of low soil fertility	Acacia bark charcoal plus fertiliser increased maize and peanut yields (but not cowpea)
Chan (2007)	Pot trial on radish yield in heavy soil using commercial greenwaste biochar (three rates) with and without N	100 t ha^{-1}increased yield x3; linear increase 10 to 50 t ha^{-1} but no effect without added N
Glaser et al. (2002b)	Cowpea on xanthic ferrasal	67 Mgha^{-1} char increased biomass 150%135 Mgha^{-1} char increased biomass 200%
Rondon (2007)	Enhanced biological N-2 fixation (BNF) by common beans through bio- char additions. Colombia	Bean yield increased by 46% and biomass production by 39% over the control at 90 and 60 g kg($^{-1}$) biochar, respectively.
Steiner (2007)	Four cropping cycles with rice (*Oryza sativa* L.) and sorghum (Sorghum bicolor L.)	Charcoal amended with chicken manure amendments resulted in the highest cumulative crop yield (12.4 Mgha^{-1})
Kimetu et al. (2008)	Mitigation of soil degradation with biochar. Comparison of maize yields in degradation gradient cultivated soils in Kenya.	doubling of crop yield in the highly degraded soils from about 3 to about 6 tons/ha maize grain yield

Source of selected references (Woolf, 2008)

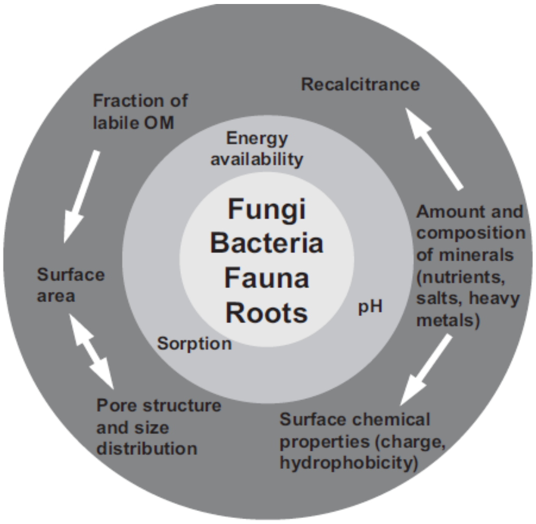

Figure 4: Schematic overview of the connection between primary biochar properties (outer circle),the soil process they may influence (intermediate circle) and the soil biota (inner circle),white arrows indicate the influence between biochar properties.

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