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Research Paper

Biochar: Its uses and effects on agriculture

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Absract: Biochar has a great potential and beneficial effect on enhancing soil fertility, carbon sequestration, crop yield, reducing nutrient leaching and greenhouse gas emissions, while enabling encourage waste disposition. Because of the potential for widespread application, it is essential to proactively assess and mitigate any unintended consequences associated with soil biochar amendment. Effects of biochar on soil fauna are even less understood than its effects on microorganisms, apart from several notable studies on earthworms. It is clear, however, that sorption phenomena, pH and physical properties of biochar such as pore structure, surface area and mineral matter play important roles in determining how different biochar affect soil biota.

BIOCHAR is defined simply as charcoal that is used for agricultural purposes. It is created by using a pyrolysis process, heating biomass in a low oxygen environment. Once the pyrolysis reaction has begun, it is self-sustaining, requiring no outside energy input. By-products of process include syngas (H_2 + CO), minor quantities of methane (CH_4), tars, organic acids and excess heat. *"Terra-Preta*" an Amazonians' primitive technology for enhancing soil productivity with charred biomass while "Biochar" a viable technique for carbon sequestration in soil (Lehmann *et al.*, 2006).Once it is produced, biochar is spread on agricultural fields and incorporated into top layer of soil. Biochar increases crop yields, sometimes substantially if the soil is in poor condition. It helps to prevent fertilizer runoff and leeching, allowing the use of less fertilizers and diminishing agricultural pollution to the surrounding environment. And it retains moisture, helping plants through periods of drought more easily. Most importantly, it replenishes exhausted or marginal soils with organic carbon and fosters the growth of soil microbes essential for nutrient absorption, particularly mycorrhizal fungi.

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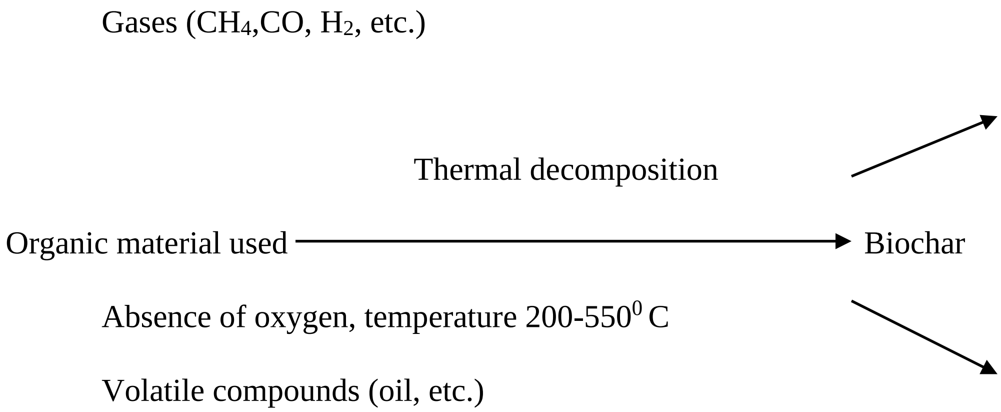

Fig 1. Schematic sketch of biochar production technique (Jha*et al*., 2010)

When biochar is created from biomass, ~50% of the carbon that plants absorbed as CO_2 from atmosphere is "fixed" in charcoal. As a material, the carbon in charcoal is largely inert and stablethat showing a relative lack of reactivity both chemically and biologically, and so it is strongly resistant to decomposition(Prabha*et al.*, 2015). Research scientists have found charcoal particles as old as 400 million years in sediment layers from wildfires that occurred when plant life first began on earth.

Biochar act as carbon sequestered technology under climate change

Biochar not originated as new but has more innovative concept and technological solution to reduce CO_2 emission and acts as 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, firstly adoption of a carbon market and secondly the market price for biochar must be low enough to make farmer friendly (Galinato*et al.*, 2011). The following point to be taken in the consideration to understand the relationship between carbon sequesteration and climate change:

- Biochar offers us a golden opportunity to remove excess CO_2 from the atmosphere and sequester it in a virtually permanent and environmentally beneficial way.
- Biochar is one of the only energy production systems that can actually sequester more carbon than it produces, thereby, creating a "carbon negative and are as economically feasible as pyrolysis or that can simultaneously have so many beneficial effects.
- Basically, biochar production (pyrolysis) effectively locks up atmospheric carbon dioxide (CO_2) by partially combusting plant material (biomass) that are continuously removing carbon dioxide from the environment as they carry out photosynthetic processes necessary for growth.
- Approximately 40% of the carbon content of the plant is locked up as biochar which becomes a safe, stable and beneficial form of soil carbon

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effectively is able to sequester large quantities of carbon on an annual basis.

- Prior to the industrial revolution there was approximately 280 ppm of carbon in the atmosphere today that number is over 394 ppm. Recent research suggests that the safe upper limit of CO_2 in the atmosphere is no more than 450 ppm. James Hansen, Director of NASA's Goddard Institute of Space Studies, has suggested that the safe upper limit of CO_2 in the atmosphere is likely 350 ppm or below.
- Ability of biochar to sequester carbon with many of these suggesting a range between 0.5 and 3.0 Gigatons (billion metric tons) of carbon per year. Approximately 9.5 billion metric tons of carbon emitted every year from the burning of fossil fuels, cement production, and deforestation, this would equate to a sequestration potential of roughly 5-30% of total global emissions on an annual basis.
- During the production of biochar from the organic residues, it prompted to eliminate pathogens and the speciation of some heavy metal contaminants into forms with reduced levels of toxicity.
- Biochar acts as alternative source as suggested by Day *et al.*, 2005 because, it scrubs CO2, 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).

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Table 1. Some properties of biochar used in different experiments

Materials used for Producing Biochar	pH	Total C (%)	Total N (%)	C: N ratio	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	P (cmol kg^{-1})	K (cmol kg^{-1})	Cation Exchange Capacity (cmol kg^{-1})	Reference
Papermill waste 1 (waste wood chip)	9.4	50.0.	0.48	104	6.20	1.20	-	0.22	9.0	Zwieten*et al.*, 2010
Papermill waste 2 (waste wood chip)	8.2	52.0	0.31	168	11.00	2.60	-	1.0	18.0	Zwieten*et al.*, 2010
Greenwaste (grass clippings,cotton trash and plant prunings)	9.4	36.0	0.18	200	0.40	0.56	-	21.0	24.0	Chan *et al.*, 2007
Eucalyptus biochar	-	82.4	0.57	145	-	-	1.87	-	4.69	Noguera*et al.*, 2010
Cooking biochar	-	72.9	0.76	96	-	-	0.42	-	11.19	Noguera*et al.*, 2010
Poultry litter (450°C)	9.9	38.0	2.00	19	-	-	37.42	-	11	-
Poultry litter (550°C)	13.0	33.0	0.85	39	-	-	5.81	-	11	-
Wood biochar	9.2	72.9	0.76	120	0.83	0.20	0.10	1.19	11.90	Major *et al.*, 2010a
Hardwood sawdust	-	66.5	0.30	221	-	-	-	-	-	Spokas*et al.* 2010

(Source: Jha*et al.*, 2010)

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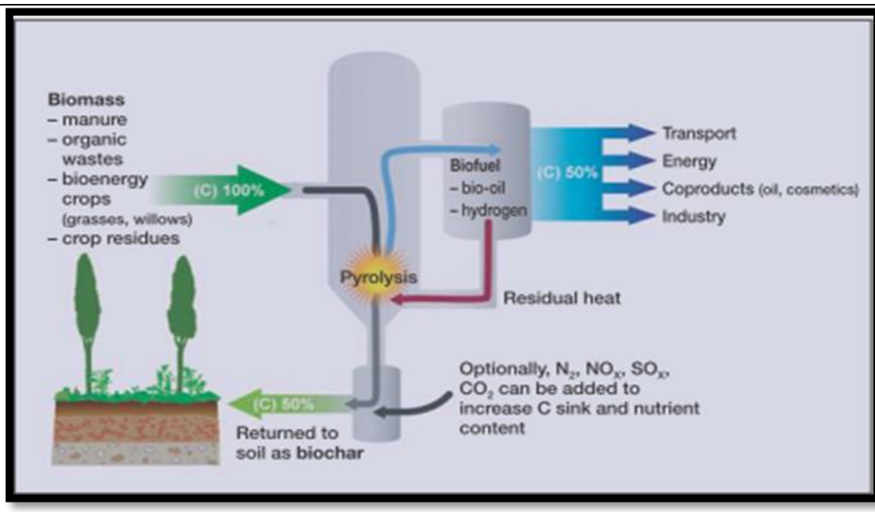
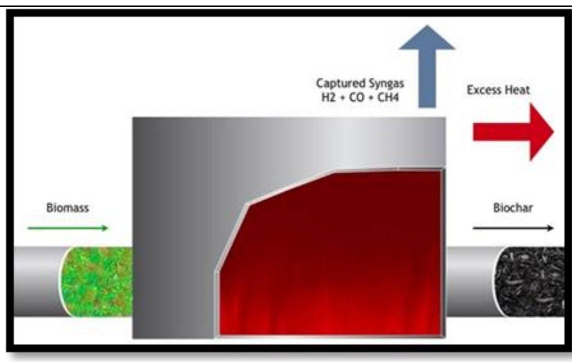
Large Scale Production of Biochar

The most suitable materials have high lignin concentration yielding the most bio-char (Demirbas 2004):

- Agricultural residues: paddy straw, wheat straw and maize stalks etc.
- Forestry residues: logging residues, dead wood, excess saplings and pole trees etc.
- Urban wastes: yard trimmings, site clearing, pallets, wood packaging, industry and municipal residues
- Nut shells : groundnut, hazelnut, macadamia nut, walnut, chestnut, coconut
- Bagasse from sugar cane processing,
- Olive or tobacco wastes (Lehmann *et al.*, 2006).



(a)



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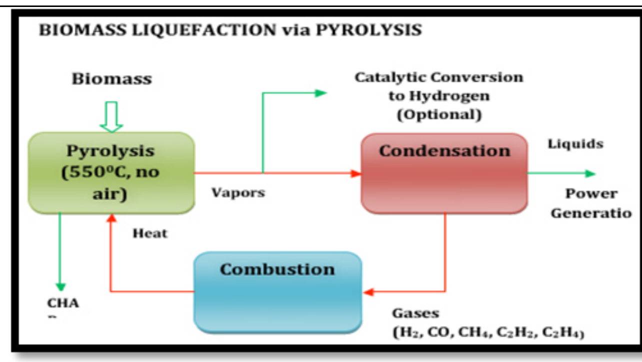

(c)

Fig 2. Schematic process of biochar preparation [(a- Processof biochar production (http://www.biochar-international.org), b- simple process of solid production(Source: http://www.biochar.info) and c-liquid preparation (https://news.mongabay.com)]

Four types of recognized pyrolysis methods for generating Biochar

- Slow Pyrolysis - traditional (dirty, low char yields) and modern (clean, high char yields)

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- Flash Pyrolysis - modern, high pressure, higher char yields
- Fast Pyrolysis - modern, maximizes bio-oil production, low char yields
- Gasification - modern, maximizes bio-gas production, minimizes bio-oil production, low char yields but highly stable, high ash content.

Table 2. Product yield in different processes

Process	Air filtration	Heat source	Temp.	Time
Slow pyrolysis	None	External	500^0 C	30 minutes
Fast pyrolysis	None	External	500^0 C	Few seconds
Gasification	20% equivalence ratio	Combustion of infiltrated air	500^0 C	Few seconds

Effect of biochar

1. Biochar andclimate change

Biochar offers us a golden opportunity to remove excess CO_2 from the atmosphere and sequester it in a virtually permanent and environmentally beneficial way.

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- Basically, biochar production (pyrolysis) effectively locks up atmospheric carbon dioxide (CO_2) by partially combusting plant material (biomass) that are continuously removing $CO_2$from environment as they carry out photosynthetic processes necessary for growth.
- Approximately 40% of the carbon content of the plant is locked up as biochar, which becomes a safe, stable and beneficial form of soil carbon effectivelyis able to sequester large quantities of carbon on an annual basis.
- Prior to industrial revolution there was ~280 ppm of carbon in the atmosphere today that number is over 385 ppm. Recent research suggests that the safe upper limit of CO_2 in the atmosphere is no more than 450 ppm. James Hansen, Director of NASA's Goddard Institute of Space Studies, has suggested that safe upper limit of CO_2 in the atmosphere is likely 350 ppm or below.
- Ability of biochar to sequester carbon with many of these suggesting a range between 0.5 and 3.0Gigatons (billion metric tons) of carbon per year. ~9.5 billion metric tons of carbon emitted every year from burning of fossil fuels, cement production, and deforestation, this would equate to a sequestration potential of roughly 5-30% of total global emissions on an annual basis.

2. Stability in soils

Chemically biochar is composed of highly stable poly-aromatic bonds which generally resist weathering and decomposition by microbial communities. "Aromacity" refers to a special form of chemical bonding in which a tightly joined ring of atoms form being held together in a series of single and double bonds which freely pass electrons between themselves thereby switching between the two bonding states continuously in a sort of intermediate

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bond. It is this chemical stability which gives biochar it's highly recalcitrant nature.While it is known that charcoal can last in the soil for decades, centuries, millennia and even tens of thousands of years, several studies suggest that there is a certain portion of freshly produced charcoal which is not so resistant to weather and that this could be readily broken down and released as carbon dioxide into the atmosphere. This is referred to as "labile" carbon, the carbon that is easily degraded, as opposed to "recalcitrant" carbon which resists degradation. Generally, labile portion of biochar is found is ~ 2-10% of the total carbon content of the biochar.Major *et al.*(2010) found that ~2.2% of carbon being lost from soil respiration while a much larger percentage of biochar (~50% in their study) is subjected to removal from the field from erosion–large-rainfall events in particular. Research is needed to determine the proportions labile and recalcitrant carbon in fresh biochar. It is likely that this may be influenced by the pyrolysis technique (e.g. slow vs. fast pyrolysis) utilized, the feedstock material used, and the temperature and residence times which the biomass is subjected to.

3. Carbon sink

- Biochar can store large amounts of greenhouse gases in ground, potentially reducing or stalling growth in atmospheric GHG levels; at same time its presence in the earth can improve water quality, increase soil fertility, raise agricultural productivity and reduce pressure on old-growth forests.
- It can sequester carbon in the soil for hundreds to thousands of years, like coal and a viable option for mitigation of global warming by greenhouse gas remediation.
- Annual net emissions of CO_2, CH_4 and N_2O could be reduced by a maximum of 1.8 Pg CO_2-C equivalent (CO_2-C) per year (12% of current anthropogenic CO_2-Ce emissions; 1 Pg=1 Gt), and total net emissions over course of a century by 130 Pg CO_2-Ce, without endangering food security, habitat or soil conservation.
- It is a high-carbon, fine-grained residue which today is produced through modern pyrolysis processes. Pyrolysis is direct thermal decomposition of biomass in the absence of oxygen to obtain an array of solid (biochar), liquid (bio-oil) and gas (syngas) products.

4. Soil amendment

- For plants that require high potash and elevated pH, biochar can be used as a soil amendment to improve yield.
- It can improve water quality, reduce soil emissions of greenhouse gases, reduce nutrient leaching, reduce soil acidity, and reduce irrigation and fertilizer requirements.
- Modest additions of biochar to soil reduce N2O emissions by up to 80% and eliminate methane emissions, which are both more potent greenhouse gases than CO2.
- Itreduces leaching of critical nutrients, creates a higher crop uptake of nutrients, and provides greater soil availability of nutrients. At 10% levels biochar reduced contaminant levels in plants by up to 80%, while reducing total chlordane and DDX content in the plants by 68 and 79%, respectively.

5. Water retention

- Biochar is a desirable soil material in many locations due to its ability to attract and retain water, because of its porous structure and high surface area.
- As a result, nutrients, phosphorus and agrochemicals are retained for the plants benefit. Plants are

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therefore healthier and fertilizers leach less into surface or groundwater.

6. Energy production: bio-oil and syngas

Bio-oil can be used as a replacement for numerous applications, where fuel oil is used, including fuelling space heaters, furnaces, and boilers. Additionally, these biofuels can be used to fuel some combustion turbines and reciprocating engines, and as a source to create several chemicals.

- If biochar is used for the production of energy rather than as a soil amendment, it can be directly substituted for any application that uses coal.
- Pyrolysis also may be the most cost-effective way of producing electrical energy from biomaterial. Syngas can be burned directly, used as a fuel for gas engines and gas turbines, converted to clean diesel fuel through the Fischer–Tropschprocess.
- The greatest potential for bio-oil seems to be its use in a bio-refinery, where compounds that are valuable chemicals, pesticides, pharmaceuticals or food additives are first extracted, and the remainder is either upgraded to fuel or reformed to syngas.

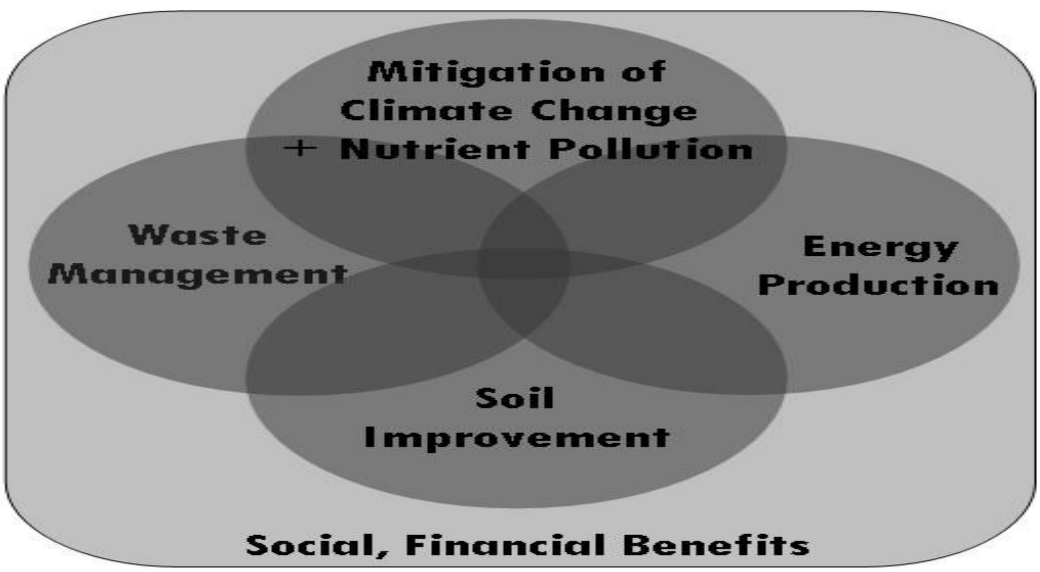

Fig.3.According to Lehmann (2007) biochar relationship with environment and agriculture concurrently with solution strategies

Currently, however, very little biochar is utilized in agriculture, in part because its agronomic values in terms of crop response and soil health benefits have yet to be quantified:

- Positive effects of biochar on productivity under conditions of extensive agriculture are frequently attributed to direct effects of biochar-supplied nutrients and to several other indirect effects i.e.increased physico-chemical and biological properties of the soil.
- Biochar addition to soil alters the microbial populations in rhizosphere, albeit *via* mechanisms not yet

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understood, and may cause a shift towards beneficial microorganism populations that promote plant growth and resistance to biotic stresses.

- Moreover, earthworms and biochar increase mineral nutrient availability through an increase in mineralization and nutrient retention respectively and are likely to interact through various other mechanisms and could thus increase plant growth synergistically.
- It-induced plant protection against soil borne diseases, the induction of systemic resistance towards several foliar pathogens in many crop systems has been demonstrated.
- It induces responses along both systemic acquired resistance (SAR) and induced systemic resistance (ISR) pathways, resulting in a broad spectrum controlling capacity in the canopy. Hence, effects of biochar as soil amendment on the different soil-plant-microbe interactions that may have a role in plant health and improvement of plant responses to disease can be one of the benefits gained from applying biochar to soil.
- Its application also improves the overall sorption capacity of soils and therefore it might influence the toxicity, transport and fate of different heavy metals in the soil.
- Microbial biomass has been found to increase as a result of biochar additions, with significant changes in microbial community composition and enzyme.
- Several principal mechanisms have proposed and partly proven for composts, including:
  - Direct release of inhibitors of plant pathogens;
  - Promotion of microorganisms that acts antagonistic to pathogens i.e. parasites, through production of antibiotics, or by successful competition for nutrients
  - Improved plant nutrition and vigour, leading to enhanced disease resistance
- Activation of plant defence mechanisms (induced systemic resistance) by enhancing certain microorganisms.

Application of biochar

In some soils, 20-25 tonnes biochar/ha have been applied with beneficial effect. It is assume that the biochar if placed in the top 15 cm of soil and that soil has a dry specific gravity of 1.2 g/cm^3. In this condition, the amount of biochar applied at the rate of 25 tonne/ha.

Concerns and criticism of biochar

- Biochar production could lead to competition with food crops and/or deforestation
- Biochar production if scaled up to the extent necessary to sequester massive amounts of CO_2 from atmosphere would lead to the establishment of vast monoculture plantations.
- Biochar production could prevent agricultural wastes from being recycled back into soils.
- Biochar can lead to faster decomposition rates of native carbon stocks in soils.
- Biochar may introduce dangerous compounds into soils.
- Poor biochar production practices could actually lead to greater greenhouse gas emissions and detrimental air quality.

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- There has been little research on biochar and we don't fully know how it will affect soils or crops.

Future Prospects

Most biochar researchers agree that the technology needs more study and that the most important thing is to reduce emissions in the first place. "Biochar is not a silver bullet for sequestration," Lehmann says. "We cannot continue the emissions that we generate today and anticipate that any technology or combination of technologies could compensate." Nevertheless, it's possible that biochar could help mitigate those emissions, he says (Lehmann *et al.*, 2006).We must answer certain questions before recommendinglarge-scale use of biochar for agriculture purposes (Jha*et al.*, 2010).

1. Before production of biochar, the question strike in the mind that the amount of carbon sequestered in the biochar biomass either taking into account of net carbon balance or not. The production in such a way that the amount of CO_2 evolved for producing biochar must be considerably less than the amount of carbon sequestered in charcoal. There must be positive carbon balance for producing biochar biomass.
2. The research on the many complex issues related to biochar production systems is growing very quickly and will be needed to fully understand the implications for food systems, the environment and bioenergy production. Finally, biochar could play an important basis for rural economic development because its production can be scaled down for smaller communities closer to biomass sources.
3. Does biochar has any effect on the soil microbial community and how they behave under the presence of a non-degrading carbon source? The known concerns of decomposers present in the soils has driven their energy from the organic matter present in the soil i.e. soil organic matter (SOM), particularly the soil heterotrophs. Thus, microbial dynamics must be taking in to account for the understanding particularly in the presence of non-degrading carbon source and vice-versa.
4. The degradation of biochar is extremely slow; therefore the mechanism behind nutrients release/availability must be understood.
5. What will be the enzymatic activity under the influence of a non-degrading substrate?
6. What should be the optimum rate and time for the application of biochar?
7. The long-term application effect of biochar on crop yield and soil quality must be pointed out? As the fact indicated that biochar also apply as soil amendment for improving soil quality and soil-carbon sequestration has attracted global attention, hence an inadequate knowledge on the long-term application, production, quality, properties and feed stock use in biochar must be ensured before using it as soil amendment and also ensured that it may be beneficial in amelioration of problematic soils.
8. Biochar has very promising potential for the further development of sustainable agriculture production systems. Also, biochar production provides a great potential for

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worldwide climate change mitigation that goes beyond its uses in agricultural production alone.

SUMMARY

Incomplete combustion of organics such as vegetation or fossil fuel led to accumulation of charred products in the upper soil horizon. Such charred products, frequently called pyrogenic carbon or black carbon (BC), may act as an important long-term carbon (C) sink because its microbial decomposition and chemical transformation is probably very slow. Biochar application to soils, therefore, may play both a global warming mitigation and a climate change adaptation role.

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