Chapter

Importance of Biochar in Agriculture and Its Consequence

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Abstract

Climate change is affecting all four dimensions of food security: food availability, food accessibility, food utilization, and food systems stability. It is also affecting human health, livelihood assets, food production, and distribution channels, as well as changing purchasing power and market flows. Keeping in view, the present chapter is focusing mostly on biochar. Biochar is usually produced by pyrolysis of biomass at around temperature range of 300–600°C. It is under investigation as an approach to carbon sequestration to produce negative carbon emissions. Present agriculture is leading mining of nutrients and reduction in soil organic matter levels through repetitive harvesting of crops. The most widespread solution to this depletion is the application of soil amendments in the form of fertilizers containing the three major nutrients. The nitrogen is considered the most limiting nutrient for plant growth useful for protein builds, structures, hormones, chlorophyll, vitamins, and enzymes. Biochar may be added to soils to improve soil health, improve soil fertility, and sequester carbon. However, the variable application rates, uncertain feedstock effects, and initial soil state provide a wide range of cost for marginally improved yield from biochar additions, which is often economically impracticable. There is a need for further research on optimizing biochar application to improve crop yields.

Keywords: soil health, soil fertility, nutrients, carbon, biochar, soil properties

1. Introduction

Natural organic biomass burning creates black carbon which forms a considerable proportion of the soil's organic carbon. Due to black carbon's aromatic structure, it is recalcitrant and has the potential for long-term carbon sequestration in soil. Soils within the Amazon-basin contain numerous sites where the "dark earth of the Indians" (Terra preta deIndio, or Amazonian Dark Earths [ADE]) exist and are composed of variable quantities of highly stable organic black carbon waste ("biochar") [1]. The intensification of agricultural production on a global scale is necessary to secure the food supply for an increasing world population. As a result, fallow periods are often reduced in shifting cultivation in the humid tropics leading to irreversible soil degradation and increased destruction of remaining natural forests due to the cultivation of new areas after slash and burn [2].

The incorporation in soils influences soil structure, texture, porosity, particle size distribution and density. The molecular structure of biochar shows a high degree of chemical and microbial stability [3]. A key physical feature of most biochar is its highly porous structure and large surface area [4]. This structure can provide refugia for beneficial soil micro-organisms such as mycorrhizae and bacteria and influences the binding of important nutritive cations and anions. This binding can enhance the availability of macro-nutrients such as N and P. Other changes in soil by biochar applications include alkalization of soil pH and increases in electrical conductivity (EC) and cation exchange capacity (CEC) [5–7]. Ammonium leaching is reduced, along with N_2O soil emissions. There may also be reductions in soil mechanical impedance. Terra preta soils contain a higher number of "operational taxonomic units" and have highly distinctive microbial communities relative to neighboring soils [8]. The apparent high agronomic fertility of these sites, relative to tropical soils in general, has attracted interest. Biochar can be produced by "burning" organic matter under low oxygen (pyrolysis). Principally biochar is produced through various thermo-chemical conversion methods such as low pyrolysis, fast pyrolysis, gasification, and torrefaction, under different process parameters [9]. The quantities of key mineral elements within this biochar can be directly related to the levels of these components in the feedstock before burning [10]. The potential importance of biochar soil incorporation on mycorrhizal fungi has also been noted with biochar providing a physical niche devoid of fungal grazers. Improvements in soil field capacity have been recorded upon biochar additions [4].

2. Applications of biochar and their effect on soil properties

Evidence shows that bioavailability and plant uptake of key nutrients increases in response to biochar application, particularly when in the presence of added nutrients. A systematic representation of the potential of biochar in soil and plant system is presented in **Figure 1**.

Depending on the quantity of biochar added to soil significant improvements in plant productivity have been achieved, but these reports derive predominantly from studies in the tropics [11, 12]. As yet there is limited critical analysis of possible agricultural impacts of biochar application in temperate regions, nor on the likelihood of utilizing such soils as long-term sites for carbon. On the other hand, soil application of biochar can permanently appropriate C in the soil and reduce net emissions of carbon dioxide gas improve crop productivity through enhanced physio-chemical and biological properties, nutrient release pattern, reduce denitrification and soil pollutants [10]. Biochar application can be a means of not only sequestering carbon in the soil but also returning essential organic matters lost with biomass removal from agro- and/or forestry systems for energy production. Thus, biochar can potentially provide two simultaneous economic benefits. One, it may improve the agronomic and environmental sustainability of biomass production systems. Two, it may improve the economic sustainability of bioenergy enterprises by offsetting feedstock purchases with revenue from biochar sales [9]. Biochar has the capacity to produce revenue and boost the sustainability of agriculture and environment. The agricultural and bioenergy industries will be reluctant to pay for biochar until its precise effects on soil properties and crop production are shown. Complete development of biochar as a commercial product

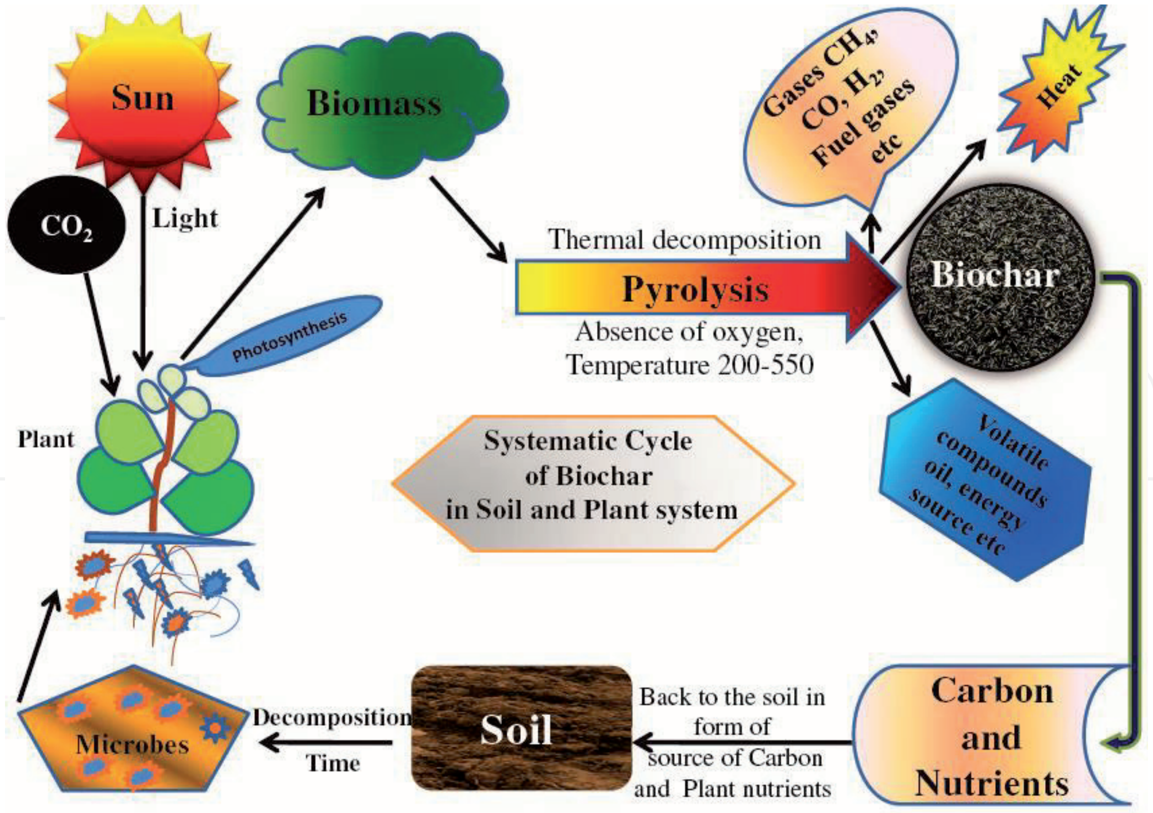

Figure 1.
Systemic potential mechanism of biochar in soil and plant system.

must establish concrete benefits of the product to soil properties and crop production and link all these benefits to biochar properties and its appropriate use and economic value. One of the most important factors to make this a reality is the understanding of how this product is made and how the production process affects its performance. Its benefits on crop production, environment, and soil will be a moot point if it is not reproducible and consistent. Biochar and its beneficial component are presented in **Table 1**.

2.1 Physical properties

Biochar itself is a porous material thus it can be adsorbed and retain a huge amount of water. Dugan et al. also reported that the maize stover biochar and sawdust biochar increased the water holding capacity (WHC) of loamy sand in Ghana when it was applied at the rate 5, 10, and 15 ton ha^{-1}. The WHC increased because small pores in biochar retain moisture and there are largely absent in coarse texture soils. The increased moisture retention depends on the higher porosity of biochar. Soils amendment with biochar is more ineffective improving WHC in sandy soils than in loamy and clay soils by improved water holding capacity [18, 19]. Pietikäinen et al. reported that two biochars, one prepared from humus and one from wood, had a similar water-holding capacity (WHC) (2.9 mL g^{-1} dry matter) than activated carbon (1.5 mL g^{-1} dry matter). Smaller pores will attract and retain capillary soil water much longer than larger pores (larger than 10–20 μm) in both the biochar and the soil. During thermal conversion, the mineral and carbon skeleton formed retains the rudimentary porosity and structure of the original material. Microscopy analysis proves the presence of aligned honeycomb-like groups of pores on the order of 10 μm in diameter, most likely the carbonaceous skeleton from the biological capillary structure of the raw material [20]. Brunauer-Emmett-Teller

Properties	Effect of biochar application on various factors	References
Soil fertility	Biochar can improve soil fertility, stimulating plant growth, which then consumes more CO_2 in a positive feedback effect.	[13]
Reduced fertilizer inputs	Biochar can reduce the need for chemical fertilizers, resulting in reduced emissions of greenhouse gases from fertilizer manufacture.	[14]
Reduced N_2O and CH_4 emissions	Biochar can reduce emissions of nitrous oxide (N_2O) and methane (CH_4), two potent greenhouse gases from agricultural soils.	[15]
Enhanced soil microbial life	Biochar can increase soil microbial life, resulting in more carbon storage in soil.	[16]
Reduced emissions from feed stocks	Converting agricultural and forestry waste into biochar can avoid CO_2 and CH_4 emissions otherwise generated by the natural decomposition or burning of the waste.	[15]
Energy generation	The heat energy and also the bio oils and synthesis gases generated during biochar production can be used to displace carbon positive energy from fossil fuels.	[17]

Table 1.
Biochar and its beneficial component in the environment.

(BET) surface areas of olive kernel biochars increased with increasing mass loss (burn-off) regardless of the activation temperature [21]. Micropores (<2 nm in diameter) are responsible for adsorption and high surface area the total pore volume of the biochar will be divided as microspores (pores of internal diameter less than 2 nm), mesopores (pores of internal width between 2 and 50 nm) and macropores (pores of internal width greater than 50 nm) [22].

2.2 Chemical properties

Soil application of biochar resulted in a significant increase in soil pH. Van et al. suggested that biochar derived from poultry litter facilitates liming in soil resulting in the rise of pH of acidic or neutral soils. Hoshi et al. in his experiment suggested that the 20% increase in height and 40% increase in the volume of tea trees were partly due to the ability of the biochar to maintain the neutral pH of the soil. Such ability is related to the liming value of the biochar. Van et al. reported a nearly 30–40% increase in wheat height when biochar produced from paper mill sludge was applied at a rate of 10 t ha^{-1} to an acidic soil but not to neutral soil. The increase in soil organic carbon with the application of biochar might have resulted from the recalcitrant nature of carbon found in biochar which is largely resistant to decomposition [1, 23–25] also reported that soil carbon increased significantly over control. Available N, P and K applying biochar to forest soils along with natural or synthetic fertilizers have been found to increase the bioavailability and plant uptake of P, alkaline metals and some trace metals [2, 19, 25] but the mechanisms for these increases are still a matter of speculation. Lehmann et al. demonstrated the ability of biochar to retain applied fertilizer against leaching with resulting increase in fertilizer use efficiency. In the manufacture of the N-enriched biochar Day et al. suggested that biochar produced at a lower temperature of 400–500°C is more effective in adsorbing ammonia than that produced at higher temperatures (700–1000°C). Total N content depends on pyrolysis temperature initially at low pyrolysis temperature N content increases which further decreases with higher temperature due to volatilization of N whereas C/N ratio of biochar (63–80) varies less with pyrolysis temperature but varies significantly with the type of feedstock material [26]. Biochar influence the dynamics of different nutrients indirectly by its high surface area and high cation exchange capacity. Changes in the dynamics of N with the application of biochar are not fully understood [27]. Weathering of biochar in soil fastens immobilization of nitrogen on its surface, studies have shown that high application rate of biochar (10% or 20%, w/w) significantly decreased NH_4 volatilization due to its high cation exchange capacity [25] but in case of NO_3^- the leaching increased especially if the initial N content of biochar is high [28]. Biochar itself is a very good source of several essential plant nutrients. Chemical, physical properties, and nutrient content status of biochar are shown in **Table 2**.

2.3 Biological activity

Ameloot et al. showed that the type of biochar alone has a significant effect on soil enzymatic activity. The quoted authors proved that poultry litter biochar produced at 400°C and amended to soil 20 t ha^{-1} caused a significant increase in the activity of dehydrogenases. Biochar has a positive effect on mycorrhizal

Parameter	**Value**		**References**
	Minimum	**Maximum**	
pH	4.5	12.9	[29]
Electrical conductivity(mS cm^{-1})	20	10,260	[30]
Cation exchange capacity (cmolþ kg^{-1})	3.8	272	[31]
Surface area (m2 g^{-1})	0.1	410	[32]
Bulk density (g cm^{-3})	0.05	0.7	[33]
Volatile matter (%)	0.6	85.7	[30]
N (g kg^{-1})	0.1	6.4	[17]
K (g kg^{-1})	0.3	74.0	[34]
P (g kg^{-1})	0.005	59	[34]
Ca (g kg^{-1})	0.04	92	[34]
Mg (g kg^{-1})	0.009	37	[34]
Carbon (%)	17.7	92.7	[35]
Hydrogen (%)	0.05	5.30	[35]
Oxygen (%)	0.01	39.2	[36]
H/C	<0.01	1.14	[30]
O/C	0.02	1.11	[36]

Table 2.
Various physico biochemical properties of biochar.

association when applied to soil [37–39] evaluated the increase in microbial biomass when biochar is applied to the soil and its efficacy as a measure of CO_2 released per.

Microbial biomass carbon in the soil increase in basal respiration due to addition of the carbon in soil. Biochar does not contribute directly to the microbial population in the soil. Hence higher porosity of biochar creates a favorable environment for microbes to make a habitat in soil [40] researchers have suggested that biochar benefits microbial communities by providing suitable habitats for microorganisms that protect them from predation [41–43]. Microbial cells typically range in size from 0.5 to 5 μm and consist predominantly of bacteria, fungi, actinomycetes, lichens, and algae species are from 2 to 20 μm [44]. The microscopic studies indicate that biochar in soil serve as habitat for microorganisms [3]. The loss of volatile and condensable compounds from biochars and the concomitant relative increase in the organized phase formed by graphite-like crystallites leads to the increase in solid density (or true density) of the round 1.5–1.7 g cm^{-3}. Increasing anthropogenic activities have mainly resulted into buildup of non-essential heavy metals in agricultural soils. Recently chromium (Cr) contamination in water and soil is a serious concern [44].

3. Application of biochar in decontamination/removal of organic pollutants from soil and water

In this era of high population and modernization, the contamination of soil and water resources due to organic contaminants is a major concern. Biochar from different sources has a porous carbons, the pore network of biochar is typically composed of micropores <2 nm, mesopores 2–50 nm, and macropores >50 nm. But, micropores and small mesopores (2–20 nm) are suggested to contribute the majority to the surface area and excellent adsorption capacity of biochar. Because of such excellent properties, it can be a good tool to remove organic pollutants from contaminated soil and water resources. There are several evidences available in the literature about the use of biochar for the removal of organic pollutants from contaminated soil and water in **Table 3** [54].

Organic contaminants	Biochar type	Mechanisms	References
Carbamazepine	Loblolly pine chips	Hydrophobic adsorption	[45]
Ethinylestradiol	poultry litter	Pore-filling	[46]
2,4-Dichlorophenoxyacetic acid	Wood chips	Surface adsorption	[47]
Diazinon	Rice straw	Hydrogen bonding with polar groups	[48]
Atrazine	Dairy manure	Partitioning	[49]
Nitrobenzene	Pine needles	Pore-filling	[50]
Humic acid	Grass	Hydrophobic interactions	[51]
Perfluorooctane sulfonate	Maize	Hydrophobic adsorption	[52]
p-Coumaric acid	Hardwood litter	Hydrogen bonding	[53]

Table 3.
Organic contaminants sorbet by different biochars and their abstraction mechanisms.

4. Application of biochar for soil carbon sequestration and mitigate GHGs emission

The current availability of biomass in India (2010–2011) is estimated at 500 Mtpa. Annual bio-manure production (in tons) is 32,582. A potential 61.1 MMT of fuel crop residue and 241.7 MMT of fodder crop residue are being consumed by farmers themselves. In India total biomass power generation capacity is 17,500 MW. At present power being generated is 2665 MW which include 1666 MW by cogeneration. Studies sponsored by the Ministry of New and Renewable Energy, Govt. of India have estimated surplus biomass availability at about 120–150 Mtpa. Of this, about 93 Mt. of crop residues are burnt each year. The generation of crop residues is highest in Uttar Pradesh (60 Mt) followed by Punjab (50 Mt). Efficient utilization of this biomass by converting it as a valuable source of soil amendment is one approach to manage soil quality, fertility, mitigate GHGs emissions and increase carbon sequestration [55]. Biochar has a condensed aromatic structure that makes it a stable solid rich in carbon content which is known to be highly resistant to microbial decomposition, thus it can be used to lock carbon in the soil. Biochar application has received a growing interest as a sustainable technology to improve highly weathered or degraded tropical soils [10]. Biochar can reduce N_2O emission from the soil which might be due to inhibition of either stage of nitrification and/or inhibition of denitrification, or encouragement of the decrease of N_2O and these impacts could occur simultaneously in a soil. Several workers have reported that applications of biochar to soils have shown positive responses for the yield of several crops. Similarly, biochar has also been found to have significant positive interaction with plant growth-promoting rhizobacteria for improving total dry matter yield of rice. Biochar from different sources has several other important roles other than the above mentioned depending on its source such as the role in plant growth enhancement, quality and quantity improvement of several crop species, improvement of water holding capacity, soil porosity, etc.

5. Biochar prospects and essential research

The global potential of biochar reaches far beyond *slash and char*. Inspired by the recreation of *Terra Preta*, most biochar research was restricted to the humid tropics. More information is needed on the agronomic potential of biochar, the potential to use alternative biomass sources (crop residues) and the production of by-products to evaluate the opportunities for adopting a biochar system on a global scale. Biochar as soil amendment needs to be studied in different climate and soil types. Today, crop residue biomass represents a considerable problem as well as new challenges and opportunities. A system converting biomass into energy (hydrogen-rich gas) and producing biochar as a by-product might offer an opportunity to address these problems. Biochar can be produced by incomplete combustion from any biomass, and it is a by-product of the pyrolysis technology used for biofuel and ammonia production [56]. The acknowledgment of biochar as a carbon sink would facilitate C-trading mechanisms. Although most scientists agree that the half-life of biochar is in the range of centuries or millennia, a better knowledge of the biochar's durability in different ecosystems is important to achieve this goal. The systematic recycling of biochar in the environment has been depicted in **Figure 2**.

Access to the C trade market holds out the prospect to reduce or eliminate the deforestation of the primary forest because using intact primary forest would reduce the farmer's C credits. It is estimated the above-ground biomass of unlogged

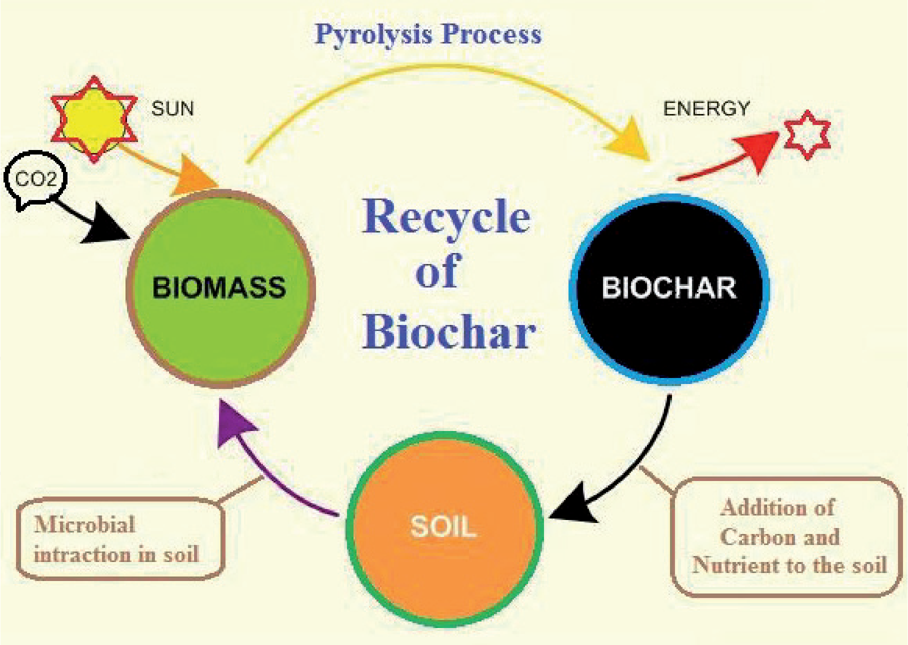

Figure 2.
Systematic recycle of biochar in the environment.

forests to be 434 Mg ha^{-1}, about half of which is C. This C is lost if burned in the slash-and-burn scenario and lost at a high percentage if used for biochar production. The Trade could provide an to cease further deforestation; instead, reforestation and recuperation of degraded land for fuel and food crops would gain magnitude. As tropical forests account for between 20 and 25% of the world terrestrial C reservoir [57] this consequently reduces emissions from tropical forest conversion, which is estimated to contribute globally as much as 25% of the net CO_2 emissions [58]. Today most biomass gasification systems tend to suppress the creation of residuals, like total organic carbon (TOC) and ashes. The C-emission trading options and a better knowledge of biochar as soil additive would add value to these residues. Further, this would facilitate the use of alternative biomass, those which are currently avoided due to their higher TOC residuals. The tarry vapors constitute a significant loss of carbon during carbonization [59] although representing another valuable product. Japanese researchers attempt to produce biochar with a specific pore size distribution to favor desired microorganisms. Pore structure, surface area, and adsorption properties are strongly influenced by the peak temperature during biochar production [59]. Increasing porosity is achieved with increasing temperature but the functional groups are gradually lost. In this context, it is also important to discern the mechanisms of nutrient retention (mainly N) due to biochar applications. The biochar's low biodegradability [60], low nutrient content [59], and high porosity and specific surface area [61] make biochar a rather exceptional SOM constituent. *Terra Preta's* research has shown that oxidation on the edges of the aromatic backbone and adsorption of other organic matter to biochar is responsible for the increased CEC, though the relative importance of these two processes remains unclear [21].

6. Conclusion

Energy from crop residues could lower fossil energy consumption and CO_2-emissions, and become a completely new income source for farmers and rural regions. A global analysis by revealed that up to 12% of the total anthropogenic C emissions by land-use change (0.21 Pg C) can be off-set annually in the soil if slash and burn are replaced by slash and char. Agricultural and forestry wastes add a conservatively estimated 0.16 Pg C $yr.^{-1}$. If the demand for renewable fuels by the year 2100 was met through pyrolysis, biochar sequestration could exceed current emissions from fossil fuels (5.4 Pg C $yr.^{-1}$). The described mixture of driving forces and technologies has the potential to use residual waste carbon-rich residues to reshape agriculture, balance carbon and address nutrient depletion.

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