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Case Study

Effect of Biochar on Agriculture and Soil Mycorrhiza

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Abstract

Biochar is a carbon rich material produced from the pyrolysis of biomass, obtained from forestry wastes, animal manures and crop residues which are the best feedstocks. A brief summary provides on the effect of biochar on soil and crop productivity. Biochar is produced through pyrolysis. Carbonization and hydrothermal carbonization of various feedstocks. Its incorporation in soil affects the physical and chemical properties which gives a new approach to achieve biological, agricultural and environmental benefits. In earlier studies researchers found it as an effective soil amendment tool as its application comprehend a new approach and has a great significance in increasing carbon storage, improving soil nutrient, soil fertility, crop productivity and maintaining the balance of soil ecosystem by their bio- physical interactions. Present study give a brief review on Biochar, different methods of production of Biochar, its uses in agriculture, its physio chemical properties, Use of Biochar in carbon sequestration, effect of Biochar on soil mycorrhiza etc. Thus, there is need to explore the study of Biochar and its production in commercial level.

***Key words*:** Biochar, Soil mycorrhiza, Carbon sequestration, Agriculture

After plant biomass has been put through the thermo-chemical conversion process (pyrolysis) at low temperatures (350-600°C) in an atmosphere with little to no oxygen, the result is biochar, a fine-grained, carbon-rich, porous substance [1]. In contrast to pure carbon, biochar is a mixture of various amounts of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulphur (S), and ash [2]. The primary characteristic of biochar and char that makes them desirable as soil amendments is their highly porous structure, which may be to blame for better water retention and an increase in soil surface area. A variety of feedstocks, including agricultural and forestry wastes, can be used to make it, including straw, nut shells, rice hulls, wood chips and pellets, tree bark, and switch grass [3]. As a potential strategy for enhancing soil fertility, potential hazardous element adsorption, and mitigating climate change, biochar has been mentioned [4]. The carbonaceous solid residue left over from heating biomass in an oxygen-deficient environment is known as biochar. It is viewed as a possible solution for long-term, healthy, and affordable carbon sequestration as well as a nutrient recycler, soil conditioner, and agro-waste recycler [5]. It has been demonstrated to be successful in enhancing soil qualities and raising crop biomass. Additionally, it has been proposed that it might improve crop disease resistance. recently been used to clean up soil that contains both organic and heavy metal contaminants [6]. The carbon in biochar is more stable in the soil environment than other organic matter and stays in the soil for hundreds to thousands of years. carbon-rich material produced by the thermochemical conversion of biomass through fast, intermediate, or slow pyrolysis or gasification in a low-oxygen environment. Unlike other organic matter, the carbon in biochar is more stable in the soil environment and remains there for hundreds to thousands of years. material that is rich in carbon that is created when biomass is thermochemically converted through gasification or fast, intermediate, or slow pyrolysis in a low-oxygen environment. Global warming, droughts, and declining soil organic carbon are just a few of the issues the globe is currently experiencing as a result of rising atmospheric CO_2 levels and climatic change. On the other hand, in order to feed the world's rapidly expanding population, there is a growing demand for food and fibre crops. In agricultural soils, adding organic carbon can boost soil fertility, which in turn can increase crop output. Additionally, by permanently storing carbon, this approach can lower the amount of greenhouse gases released into the environment [7]. Recently, biochar has drawn significant interest because it has been suggested that its creation and presence/storage in soils can help to slow down climate change by storing carbon while also supplying energy and boosting agricultural yields. One remedy to this issue is the application of biochar in nutrient-poor soil. Due to its many potential advantages for agriculture and the environment as well as its capacity to store soil water, the manufacture of biochar from agro-environmental waste biomass is generating a great deal of attention as a low-cost supplement.

Preparation of biochar

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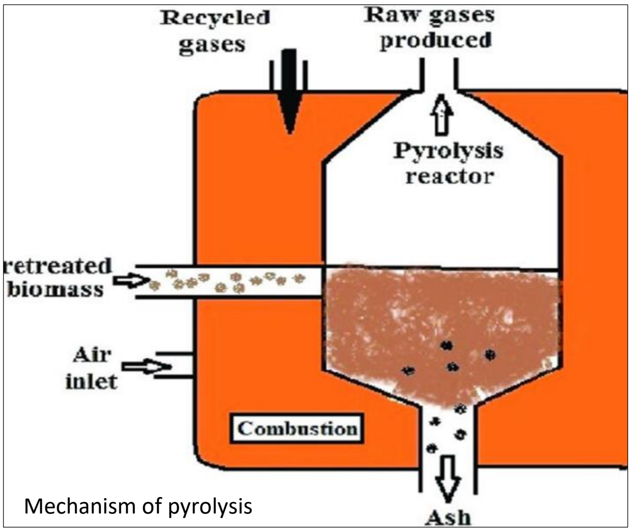
Kiln: the conventional method of making biochar.

Retorts and converters: Retorts or converters are the terms used to describe industrial reactors that have the ability to recover and refine not just biochar but also products from volatile fractions (liquid condensates and syngases). Retorts are reactors with the capacity to pyrolyze piles of wood, or logs of wood that are at least 30 cm long and 18 cm in diameter [10]. Biochar is created by converters by carbonizing small biomass particles, such as pelletized or chipped wood.

Slow pyrolysis: refers to a procedure that produces biochar by gently heating large biomass particles in the absence of oxygen.

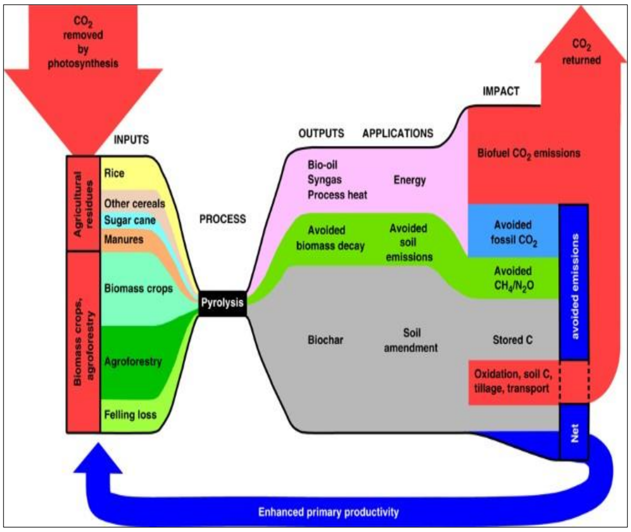
Fast pyrolysis: refers to reactors that use powdered biomass as their typical feedstock and are designed to maximize bio-oil output.

Creating a low-cost biochar kiln at the community level or a low-cost biochar stove for each farmer's household is essential for popularizing biochar technology among farmers [11].



Mechanism of pyrolysis

Source: Yaashikaa *et al*. [8]



Source: Woolf *et al*. [9]

Heap method

The heap method of producing charcoal is typically used because it is simple and incurs very little expense. To make a paste that will be mixed with clay soil and used to cover a building holding wood logs, waste coconut fibre, paddy straw, or any other suitable agricultural waste is typically used. Finally, it is covered with outside sand and drenched with water. Whole wood logs are transformed into charcoal after burning for three to four days inside the heap [11].

Source: Nabukalu and Gieré [12]

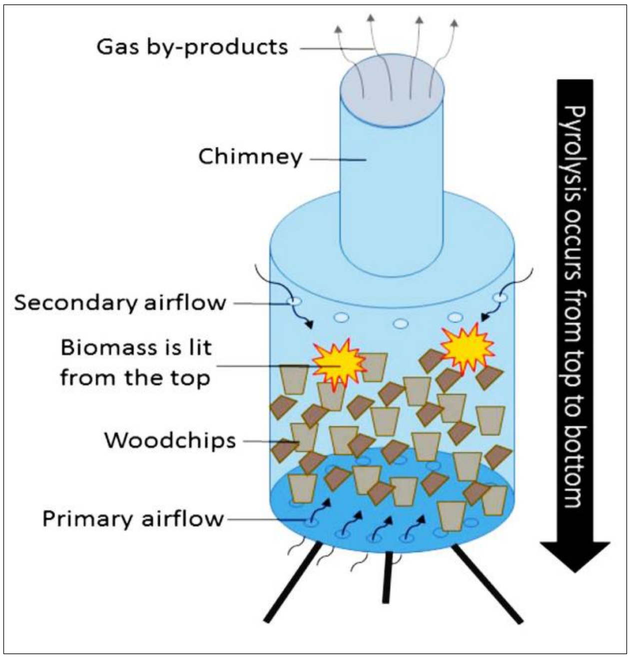
Drum method

At CRIDA, Hyderabad, Venkatesh *et al*. [13] created a low-cost charring kiln by altering oil drums. A 200 L capacity cylindrical metal oil barrel with both sides intact was purchased from a nearby market and adapted for use as a charring kiln. On the top side of the drum, a 16 cm × 16 cm square hole was drilled to load the agricultural wastes. In order to promote even air circulation from below, 36 holes overall, each measuring 4 cm^2, were drilled in concentric rings on the opposite side (bottom) of the oil drum, with a 5 cm^2 hole at the centre covering 20% of the total surface area.

Source: Venkatesh *et al*. [14]

Top-lit up draft (TLUD)

Drum pyrolyzers are the most effective, economical, environmentally benign, and farmer-friendly technique of producing biochar. The TLUD (Top Lit Up Draft) drum pyrolyzers in figure 2 are the most typical ones. Though the classic TLUD method is used to produce biochar, which yields 10%–22%, it is a straightforward and popular approach since it is inexpensive to build compared to other reactors and simple to use at home. But TLUD biochar's characteristics are invariably different for a wide range of reasons [15].



Source: Smith Adam [16]

Production of biochar

A combination of suitable pyrolysis conditions, particularly temperature and type of feedstock, should be chosen for the quality of biochar needed for agricultural and environmental purposes, according to the production yield of various materials [17]. The majority of biochars mentioned in the literature have an alkaline pH. Few biochars created from pinewood or black locust wood, on the other hand, showed a pH range of neutral to slightly acidic. As a result, the pine wood biochar can be used as a soil supplement more successfully in alkaline soils. In addition to the carbon, biochar also includes some crucial plant nutrients like P and K. Consequently, adding biochar to agricultural soils could lessen the requirement for artificial fertilizers. Due to the larger surface area of biochar, it may help lessen the loss of plant nutrients from soil with irrigation water. Biochar made from manure often has a greater P content than biochar made from crop residue or grass. Contrarily, biochars formed from agricultural residue and grass have a higher K content than those made from manure.

Brazil produces 9.9 million tonnes of biochar annually, making it the world's largest producer. Thailand (3.9 million tons/year), Ethiopia (3.2 million tons/year), Tanzania (2.5 million tons/year), India (1.7 million tons/year), and the Democratic Republic of the Congo (1.7 million tons/year) are further significant producers of biochar [11]. A top-lit updraft gasifier was used to create biochar from rice husk, and the efficiency was found to be between 15 and 33%. This technique may be utilized quite readily by farmers to make biochar on the farm [18].

Physico-chemical properties of biochar

The primary controlling factor that controls the surface area of biochar is the pyrolysis temperature. According to a study by Gopinath and Wakudkar [11], biochar's surface area grew from 120 to 460 m^2 as the temperature rose from 400 to 900 °C [19]. The soil pH of treatments receiving biochar in a greenhouse experiment by Matsubara *et al*. [20] increased from 5.4 to 6.2 (10% biochar by volume) and 6.3 (30% biochar by volume). These pH values fall within the pH range (5.5 to 7.0) where plant nutrients are almost fully available in agricultural soils, according to Lucas and Davis [21].

The three processes of pyrolysis/carbonization, gasification, and liquefaction, which all produce products in three phases of solid, liquid, and gas, depending on the process parameters, are the three ways that anaerobic thermal conversion of biomass can be accomplished [22]. Reviews by Atkinson *et al*. [23] and Joseph *et al*. [24] provided an overview of how these qualities and the subsequent interactions in soil were impacted by pyrolysis temperature. Alternative methods have been investigated for the manufacture of char in addition to traditional pyrolysis procedures. These include pressure pyrolysis [25], microwave pyrolysis [26], hydrothermal carbonization [27-29].

PHYSICAL PROPERTIES	CHEMICAL PROPERTIES	BIOLOGICAL PROPERTIES
• Decreases bulk density, improves soil workability, reduces labor and tractor tillage and minimizing fuel emissions • High negative charge of biochar promotes soil aggregation and structure • Positive effect on crop productivity by retaining plant available soil moisture due to its high surface area and porosity.	• Liming effect provides net carbon benefit compared to standard liming • Enhance the fertilizer use efficiency , reduce the need for more expensive fertilizers and improves the bioavailability of phosphorus and sulphur to crops • Reduce leaching of nutrients and prevents groundwater contamination • Carbon negative process, stable carbon , longer residence period and reduces Green House Gas emissions from soil	• Enhances the abundance, activity and diversity of beneficial soil bacteria, actinomycete and arbuscular mycorrhiza fungi • High surface area, porous structure and nutrient retentive capacity of biochar provides by protecting favourable micro- habitats by protecting them from drought, competition and predation

Effect of biochar on soil mycorrhiza

Along with ectomycorrhizal fungi (ECM) and ericoid mycorrhizal fungi (ERM), soil microbes, particularly arbuscular mycorrhizal fungi (AMF), play important roles in terrestrial ecosystems [30-33]. Since they are regularly employed as soil inoculum supplements, mycorrhizal fungi are frequently incorporated in management [34]. There are chances to take advantage of a potential synergism that could improve soil quality since both charcoal additions and mycorrhizal abundance are responsive to management techniques. Experiments showed that adding biochar to growth media had an impact on both the ECM and ERM fungi's capacity to colonize host plant seedlings and the overall growth of the host plants in seedling.

Activated carbon (AC), which in many cases has qualities comparable to biochar, also had an impact on the time of host plant colonization by ECMF, which happened 4 weeks earlier in the activated carbon treatment than in the control, according to an experiment done by Herrmann *et al*. [35] (. A few investigations found negative impacts, in contrast to the tests that showed favourable benefits of adding biochar or activated carbon on the quantity of mycorrhizal fungus. In these instances, it appears that nutritional impacts played a major role in the deleterious effects of the biochar or activated carbon inputs on AMF. In contrast to rates from plants grown in soil, Gaur and Adholeya [36] discovered that the biochar media restricted the quantity of P taken up by host plants and granules of river sand or clay-brick, indicating that P was not as readily available.

Although the effectiveness of mycorrhizas for phytoextraction and Phyto-stabilization is well established, there is currently a paucity of research on biochar treatments in relation to these amelioration strategies. The effects of wood ash addition (5,000 kg ha^1) on the growth of ectomycorrhizal Scots pine (*Pinus sylvestris* L.) seedlings in the presence of enchytraeid worms were examined in laboratory investigations by Liiri *et al*. [37] using acidic coniferous forest soil (*Cognettia sphagnetorum*). The wood ash was found to have a negative impact on seedling biomass, which was not overcome by either the mycorrhizal fungi or worms alone but only by the two together. This highlights the complexity of the relationship between the two organisms, in contrast to an earlier report by

Mahmood *et al*. [38] that found positive impacts on ectomycorrhizal spruce seedlings in matter with soil interaction. Growth, root morphological attributes, physiological characteristics, and soil enzymatic activities of spinach plants were all markedly improved by the combined application of biochar and AMF [39]. Biochar can operate as a refuge for beneficial soil microorganisms like mycorrhizae and bacteria and can have an impact on the binding of significant nutritional cations and anions due to its extremely porous structure and huge surface area [40]. Although the actual use of charcoal is limited due to its expensive cost, that "the theory that the application of charcoal stimulates indigenous arbuscular mycorrhiza fungus in soil and so enhances plant growth is pretty well-known in Japan" [41].

Use of biochar in agriculture

Study outline	Summary	Authors
Pea, India	Char at 0.5 t/ha increased biomass by 160%	Iswaran *et al*. [42]
Mungbean, India	Char at 0.5 t/ha increased biomass by 122%	Iswaran *et al*. [42]
Soybean on volcanic ash loam,	Char at 0.5 t/ha increased yield by 151%, Char at 5 t/ha decreased yield by 63%, and Char at 15 t/ha decreased yield by 29%	Kishimoto and Sugiura [43]
Sugi trees on clay loam, Japan	Wood charcoal, bark charcoal and activated charcoal at 0.5 t/ha increased biomass by 249, 324 and 244%, respectively	Kishimoto and Sugiura [43]
Bauhinia trees on Alfisol/Ultisol	Charcoal application increased biomass yield by 13% and height by 24%	Chidumayo [44]
Cowpea on xanthic ferralsol	Char at 67 t/ha increased biomass by 150% Char at 135 t/ha increased biomass by 200%	Glaser *et al*. [45]
Soil fertility and nutrient retention. Cowpea was planted in pots and rice crops in lysimeters, Brazil	Biochar additions significantly increased biomass production by 38 to 45% (no yield reported	Lehmann *et al*. [46]
Comparison of maize yields between disused charcoal production sites and adjacent fields, Ghana	Grain and biomass yield was 91 and 44% higher on charcoal site than control.	Oguntunde *et al*. [47]
Maize, cowpea and peanut trial in area of low soil fertility	Acacia bark charcoal plus fertilizer increased maize and peanut yields (but not cowpea)	Yamamoto *et al*. [48]
Pot trial on radish yield in heavy soil using commercial green waste biochar (three rates) with and without N	Biochar at 100 t/ha increased yield x3; linear increase 10 to 50 t/ha, but no effect without added N	Chan *et al*. [49]
Enhanced biological N_2 fixation (BNF) by common beans through biochar additions, Colombia	Bean yield increased by 46% and biomass production by 39% compared to control at 90 and 60 g biochar/kg, respectively	Rondon *et al*. [50]
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 t/ ha)	Steiner *et al*. [51]
Mitigation of soil degradation with biochar. Comparison of maize yields in degradation gradient cultivated soils in Kenya.	doubling of maize grain yield in the highly degraded soils from about 3 to 6 t/ha	Kimetu *et al*. [52]

Biochar for climate change mitigation

By using photosynthesis to create organic matter, atmospheric CO_2 is removed from the atmosphere and eventually stored in the soil as long-lasting, stable forms of carbon. The Earth's system's carbon flows and carbon reservoirs make up the global carbon cycle. Terrestrial, atmospheric, oceanic, and geological reservoirs of carbon are significant. These pools' carbon have different lifetimes, and fluxes occur among them all. The active carbon pool's carbon transfers carbon quickly between pools [53]. Carbon can easily move from the active pool to the passive pool with the help of biochar. Controlled carbonization, as opposed to burning, produces stable C pools from even greater amounts of organic biomass, which are thought to last for generations [54-56]. Approximately 50% of the carbon in biomass is sequestered when it is converted to biochar, as opposed to the small amounts that are retained after burning (3%), and biological degradation (less than 10%–20% after 5–10 years) [57]. The kind of feedstock has a major impact on the efficiency of carbon conversion of biomass to biochar, whereas the pyrolysis temperature (often between 350 and 500 °C) has little impact. Terra preta soils show that biochar can have carbon storage stability in the soil for many hundreds to thousands of years Gaunt and Lehmann [58]. Biochar contains significant amounts of carbon that might be stored in the soil for a very long time—possibly hundreds or even thousands of years [59]. Carbon is stored for a longer period of time in biochar than it is in other terrestrial sequestration methods like afforestation or reforestation [60-61]. The current slash-and-burn method significantly damages the soil and emits greenhouse gases. However, by switching from the slash-and-burn approach to the slash-and-char system, it also offers potential for improvement. If the slash-and-burn system is replaced with the slash-and-char system, almost 12% of the total anthropogenic carbon emissions by land-use change (0.21 Pg C) can be offset annually in the soil. Inherent recalcitrance, spatial separation of decomposers and substrate, and creation of contacts between mineral surfaces are the main mechanisms at work in soils via which biochar entering the soil is stabilized and considerably increases its residence period [62]. It is been observed that in a fifteen-week investigation on the carbon stability of biochar, carbon loss ranged from 2.34% in maize biochar to 4.49% in rice biochar. The maize biochar had the least carbon mineralization of the biochars, indicating a higher potential for long-term carbon sequestration. The wheat-pearl millet cropping system demonstrated the largest quantity of carbon in soil after applying biochar [63].

CONCLUSION

In developing countries, crop residue has traditionally been used as animal feed. When not used as animal feed, it becomes a huge surplus biomass, and farmers burning it create a hazy and smoky environment. Conversion of such surplus biomass into biochar circumvents this problem and creates employment and economic opportunities. Quality biochar with high fixed carbon content can be produced by maintaining a reactor temperature between 400 and 600 °C. It is highly porous, has a larger surface area for absorbing soluble organic and inorganic nutrients and provides a favourable environment for the growth of useful microbes. It significantly increases microbial biomass carbon in soil compared with chemical fertilizers. Biochar is also considered a carbon sink and absorbs atmospheric carbon dioxide; hence, it is a good sink for carbon sequestration. Biochar remains in soil longer if its oxygen-to-carbon (O/C) molar ratio is < 0.2. The effect of biochar on crop yield has also been discussed, and most short-term studies have reported improvements in crop yield. The long-term effects of biochar on soil health are unknown and require further study. Biochar amendment has attracted a fair amount of research interest due to its abundant usage and wide potential, which includes enhancing crop production by improving soil fertility, decreasing greenhouse gas emissions, and increasing soil carbon sequestration. Use of biochar for environmental and agricultural systems is one viable option that can increase soil quality, enhance carbon sequestration, and reduce various farm wastes.

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