Chapter 9
Production of Biochar Using Top-Lit Updraft and Its Application in Horticulture

Chandan Singh, Priya Pathak, Neelam Chaudhary, and Deepak Vyas

Abstract Biochar is a charcoal, rich in carbon, produced by typically burning organic residues of plants and animals to more than 250 °C in a low-oxygen environment. It could be efficiently produced by the various methods, but the top-lit updraft (TLUD) method is the most affordable at each farm level in agriculture. Several controlling factors determine the distinctive quality of biochar; however, the agricultural application of biochar is precisely beneficial if applied appropriately. It increases the water retention capability of the soil and cation exchange rates and holds the nutrient-holding capacity and reclamation of acidic soils. Moreover, biochar could also endure an efficient way to sequestrate carbon and a valuable agent for sustainable agriculture.

Keywords Biochar · Horticulture · Sustainable agriculture · Carbon · Charcoal

9.1 Introduction

Biochar is a carbon-charcoal product obtained by combusting biomasses like wood, manure, leaves, or animal debris in a closed container with little or no available air, or biochar is the substance obtained by thermoconversion of organic substrates in the limited presence of oxygen and at a temperature range of 250 ºC–700 ºC (Nartey & Zhao, 2014; Pathak et al., 2020). The production of biochar and its application in agriculture is thought to be a suitable method of mitigating climate change while fertilizing soil (Nartey & Zhao, 2014). Conversion of biomass to biochar is reported to be producing sustainable renewable energy and is found to reduce carbon dioxide content in the atmosphere (Carpenter & Nair, 2012; Kavitha et al., 2018; Lehmann, 2007). Historically, biochar has been traced in the Amazonian River basin (with highly dark fertile soil) that indicates the uses of biochar in ancient agricultural

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practices (Leverett, 2008). These dark, fertile soils were called terra preta (USBI, n.d.). The older people used to set a pile of organic material on fire directly and cover the pile with clays before burning to delimit oxygen but hold the heat to bake the piled-up organic materials. Charcoal is also formed naturally due to forest fire and intentionally by humans in burn pits or handmade structures. When this charcoal is added to the soil as a soil amendment, it is termed “biochar.” Though biochar production using the traditional methods is beneficial, it has demerit too, because it is not an environmentally friendly practice as it releases a huge smoke and dust particulates in the atmosphere (USBI, n.d.). The modern technology of biochar production is based on organic materials and the nature of the application (Nartey & Zhao, 2014). Usage of biochar in the soil as a fertilizing agent is beneficial for plant health. It improves the physical and chemical properties of the soil by preventing the leaching of nutrient from the soil (Jien, 2018; Jyoti Rawat & Sanwal, 2019; Sánchez-Monedero et al., 2019). Production methods, chemical properties, physical properties, and combined application of biochar in horticulture crops have been discussed here, with an emphasis on the production of biochar using the TLUD method at the farm level.

9.2 Methods of Biochar Production

It has already been mentioned that biochar is typically obtained from various biomasses by thermal degradation under different operating conditions. The process like pyrolysis and carbonization converts biomasses into bioenergy. Biochar is produced economically by three pyrolysis modes, i.e., fast, intermediate, and slow (Panwar et al., 2019). It is a fact that biochar yield is higher in slow methods than in other pyrolysis modes (Kung et al., 2015). The biochar production system can be classified as shown in diagram below (Fig. 9.1).

Depending upon the need for biochar and the costs of biochar production plant and efficacy, the specialized production process is carefully selected. The efficient TLUD method of biochar production is cost-effective, portable, and locally available for any farmer who ideally wants to produce biochar (Fig. 9.2). Though biochar production yields 10–22% by employing the TLUD method, it is a simplified and widely used method. Further, TLUD biochar is inevitably varied in its properties for a considerable variety of reasons (Masís-Meléndez et al., 2020; Panwar et al., 2019).

9.2.1 Properties and Characteristics of Biochar

Properties and distinguishing characteristics of biochar depend on many factors that affect the nature of biochar. The physiochemical properties of the biochar significantly depend on the types of feedstock used for its production and the method adopted for pyrolysis. The temperature plays a substantial role in biochar physical

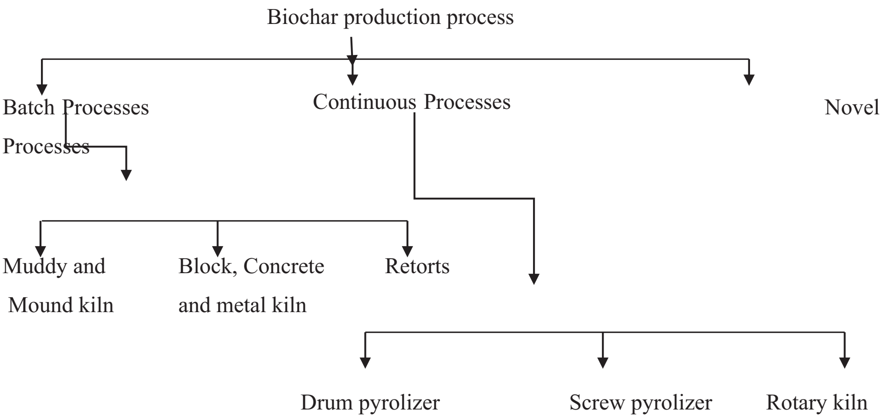

Fig. 9.1 Classification of the biochar production process (Source: Panwar et al., 2019)

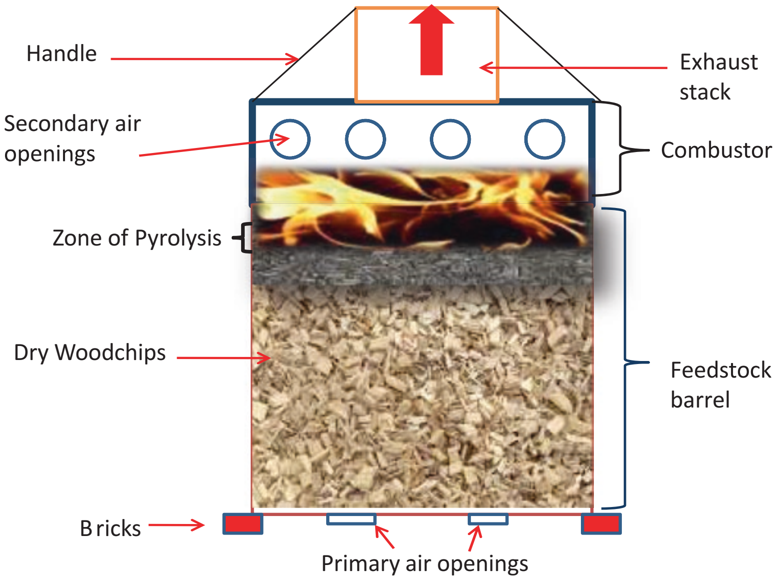

Fig. 9.2 Showing schematic diagram of TLUD workings and construction method using a barrel

and chemical nature, e.g., biochar produced at low temperature has a small pore size and low hydrophobicity compared to the biochar produced at high temperature (Jien, 2018; Masís-Meléndez et al., 2020; Suman & Gautam, 2017). The biochar production parameters depend on what is desired. Higher the processing temperature, lesser biochar will be produced but will have higher carbon stability (Retrieved from. https://biochar.international/the-biochar-opportunity/biochar-production-and-by-products, n.d.). A detailed account of the physical and chemical properties has been discussed in the subsections below.

9.2.1.1 Physical Characters

Every matter has its own physical and chemical properties, so biochar too possesses physical and chemical properties. The properties like the surface area, charge, density, structure of pores, and distributions are the essential physical features of biochar (Jien, 2018). Lehmann and Joseph (2009) mentioned that the physical properties of biochar are influenced by operating parameters, like processing heating rate, highest treatment temperature, pressure, reaction residence time, and the flow rate of ancillary inputs, irrespective of the type of feedstock. Morphological analysis of biochar by SEM microscopy reveals that more pores are present in the biochar produced under high pyrolization temperature than low pyrolization temperature (Jien, 2018). Research shows that increasing pyrolysis temperature increases the BET (Brunauer-Emmett-Teller) surface area and enhances pore development (Billa et al., 2019; Jien, 2018; Major, 2010; Suman & Gautam, 2017). The most common physical properties of fresh and aged biochar are:

I. Bulk density
II. Particle density
III. Porosity (micro and macro)
IV. Water-holding capacity
V. Grindability
VI. Surface area
VII. Hydraulic conductivity
VIII. Playability

9.2.1.2 Chemical Characters

If a user wants to use biochar as a soil amendment, he must be aware of the high variability of its chemical properties (Evans et al., 2017). The chemical properties of individual and mixed-feedstock derived biochar possess significant spatio-temporal variabilities (Nartey & Zhao, 2014). Some of the chemical characteristics of biochar are:

I. It contains macro- and micronutrients.
II. Soluble in organic solvents.
III. Shows proton activity.
IV. Has variability in EC.
V. Contribute in liming.
VI. Has cation and anion exchange capacity.
VII. Has high absorptivity.

Chemical properties of the biochar must be recognized to check whether the biochar to be used as a root substrate is under a suitable range of applications; otherwise, biochar may negatively impact plants. A study by Evans et al. (2017) compared the chemical properties of biochar manufactured from poultry litter produced at 400 °C for 2 hours in a muffle furnace which has higher macro- and microelements than the biochar made from mixed hardwood species. The chemical properties of biochar also vary with the type of biochar produced from their respective feedstocks (Evans et al., 2017; Nartey & Zhao, 2014; Panwar et al., 2019). Therefore, it is imperative to know the chemical properties of biochar before its application in the soil for better results.

9.3 Biochar as a Soil Amendment

The soil physicochemical property determines the growth of the plants and their nutrient availability. A balanced ratio of the macro- and micronutrient is essential for nutrient mobility, and soil microflora plays a substantial role in this regard. Therefore, before the amendment of soil, the user must grasp the underlying principles of soil requirement and the physicochemical properties of the amendment agents. The application of the amendment agent also executes a leading and crucial driver in the effectiveness of the amendment agent. When it comes to applying biochar to the soil to improve its fertility, the ideal application of biochar is nearer to the soil surface of the root zone, where the recycling of the nutrients and uptake is high and actively used by the plants. Besides this, it is equally important to select the specific cropping systems. The purpose of biochar application determines the application method; for purposes like carbon dioxide sequestration and moisture management, biochar must be applied in layers below the root zone. If it is to be used solely for carbon sequestration, it must be placed deeper in the soil to obtain good results (Major, 2010). The oxygen-to-carbon ratio of biochar and feedstocks, along with the condition of biochar production, determines the stability of biochar (Panwar et al., 2019). Biochar may have more than 100 years half-life time if the oxygen-to-carbon molar ratio (O:C) is more significant than 0.6, and when the ratio lies between 0.2 and 0.6, then half-life is between 100 and 1000 years; if it is less than 0.2, then the half-life is more significant than 1000 years (Spokas, 2010).

9.3.1 Biochar Impact on Soil Physicochemical Properties

Depending upon the nutrient content of the soil, the physiochemical soil properties change when biochar is added to it. The increasing population has influenced the agricultural systems, elevating the disintegration of humus and ultimately destroying soil physical properties (Aslam et al., 2014). Moreover, the non-judicious use of inorganic fertilizer has polluted the soil and has altered the physiochemical balance of the soil (Massah & Azadegan, 2016; Bista et al., 2019). Therefore, it is a matter of concern to improve the soil physicochemical properties and the fertility of the arable soil by adding substances like carbon-rich biochar (60–80%). It could enhance soil properties (Fig. 9.3) and affect soil components (Mensah & Frimpong,

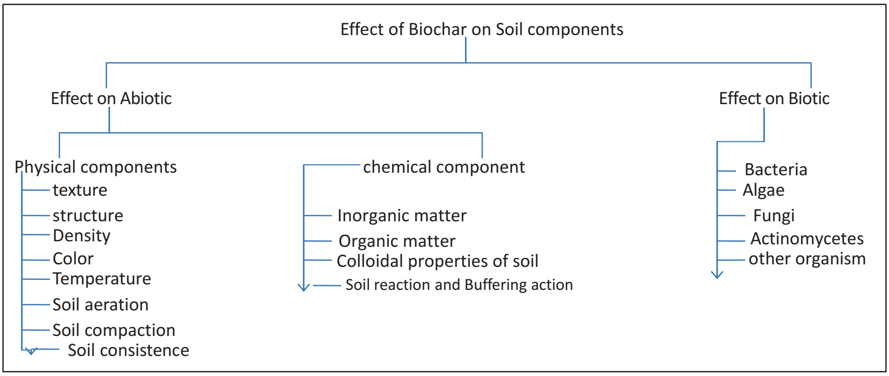

Fig. 9.3 Different components of soil where biochar could interact with each other to execute soil functions

2018). Recent experimental research has established that biochar could be an excellent soil conditioner if applied to agricultural soils (Adekiya et al., 2020; Egamberdieva et al., 2019; Egamberdieva et al., 2017). When it comes to the soil physical properties, the integration of biochar has been reported to elevate its aggregation ability, water-holding capacity, saturated hydraulic capacity, water retention and porosity (Kavitha et al., 2018; Bista et al., 2019). Generally, coarse-textured soil is more benefited by the addition of biochar than fine-textured soil. Sandy soils also show more response than clay-rich soils (Blanco-Canqui, 2017). The particle size of biochar and the depth of its application highly affect the overall water-holding capacity (Kavitha et al., 2018). According to Ibrahim et al. (2017), the particle size of biochar ranging from 0.5 to 1.0 mm increases the water-holding capacity when added to sandy soils. It also affects the soil water retention capacity (Blanco-Canqui, 2017). In a study carried out by Kameyama et al. (2016), it was observed that the greater than 3% concentration of biochar applications could increase the water-holding capacity of clay soil by 60%, therefore playing a pivotal role in the water-holding capacity and as a soil moderator. When >5% concentration is added to sandy loam soils, it decreases the size of the pores and affects the hydraulic conductivity (Kavitha et al., 2018). Amendment of biochar in the soil is found to improve soil fertility by facilitating the biochemical cycling of nitrogen and phosphorus (Gul & Whalen, 2016). Due to the high residence time and stability of biochar, it has a slow rate of decomposition in the soil and resides in the soil for a longer time. In addition, to the benefits described above, biochar also affects various other physical properties of a soil, such as swelling/shrinkage, tensile strength, surface area, and cracking density (Aslam et al., 2014; Blanco-Canqui, 2017; Kavitha et al., 2018). It imparts a positive response to the activity of soil enzymes; however, the repercussions of biochar on soil enzyme levels are yet to be assessed (Kavitha et al., 2018). Having absorptive properties, biochar suck up the heavier metal from the contaminated and toxic soils (Kameyama et al., 2016). The surface area of biochar acts as an interaction site for many of the organic as well as inorganic ions of soil and prevents leaching of the biologically available nutrient while making them available for plant growth and development (Mensah & Frimpong, 2018). Moreover, biochar provides a good niche for microbial flora of soil and nutrients to thrive in the soil which maintains the soil complex system. The impact of biochar on the soil microorganisms has been discussed below.

9.3.2 Impact of Biochar on Soil Microorganisms

Since biochar has several pores, it provides a good niche for the microbes of the soil. However, till today the mechanism of biochar, soil organic matter, and soil biota interaction has not been thoroughly analyzed. Much literature explains the mechanism of interaction of soil microorganisms and biochar (Gorovtsov et al., 2020). Still, the possible biochar-microorganism interaction mechanism includes the toxicity and volatile organic compounds that act on the soil microorganisms and the other mechanism. It influences the soil microorganism indirectly by affecting the soil properties, managing the nutrient availability and modifying the enzymatic activities (Ameloot, 2013). These interactions do not work separately but influence each other to some extent. The hydrophobicity and surface chemistry of biochar play a significant role in the attachment of the microorganisms. It has also been reported that microorganisms attach quicker to hydrophobic nonpolar surfaces than hydrophilic ones (Gorovtsov et al., 2020). The composition of biochar determines the colonization of microbes over the biochar, and the structure and composition of biochar are greatly influenced by the feedstocks, residence time, pyrolysis reactor temperature, etc. Other factors such as soil physiochemical properties, the abundance and composition of the consortia of the pre-existing microbes in the soil, and the biochar-soil contact time are the primary factors that affect the microorganism in the soil when biochar is added (Agegnehu et al., 2016; Hussain et al., 2018; Nartey & Zhao, 2014). It has been seen that aged biochar favors the abundance of microorganisms; this is because biochar provides shelter and carbon sources and maintains the favorable conditions for microbes growth (Fig. 9.4). Egamberdieva et al. (2016) observed that when biochar was incorporated in the soil to check its effects on the development of soya beans, the microbiome shifted in root-associated beneficial bacteria and resulted in improvement of plant growth. Similarly, in a study where biochar was added consecutively for 4 years in the soil, increased microbial biomass carbon and nitrogen was observed. Despite the positive effects of biochar on microbes, it has some negative impact due to the toxic chemical components of biochar (Gorovtsov et al., 2020; Spokas, 2010).

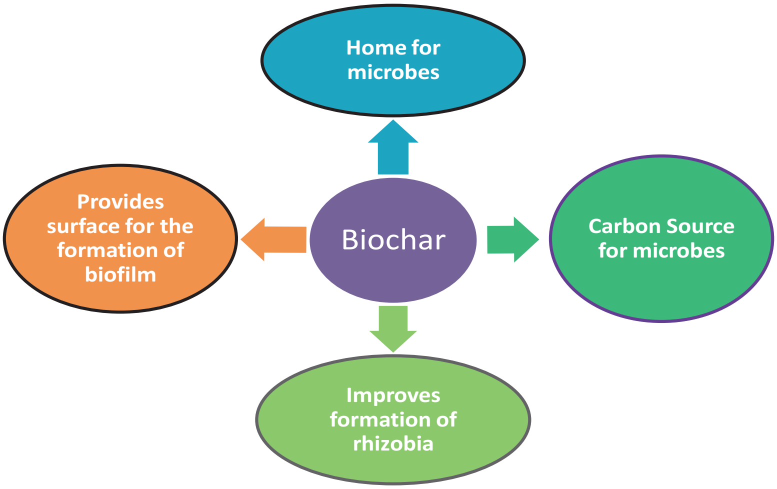

Fig. 9.4 Role of biochar for the soil microbes

9.3.3 Application of Biochar in Horticulture

"Horticulture is the science and art of development, sustainable production, marketing, and use of high-value, intensively cultivated food and ornamental plants" (Michigan State University, n.d.). Horticultural crops are varied, including annual and perennial species, fruits and vegetables, and decorative indoor and landscape plants. We are aware of the physical and chemical parameter of biochar, production methods, and how it facilitates soil physicochemical properties and its role on soil microbiome. Knowing all these facts, biochar could be an effective soil conditioner in the horticultural sector. Its use in horticulture got huge attention in recent times due to its positive effects on pH and its ability to enhance the cation exchange capacity (Blok et al., 2016). Mixtures of biochar and other different substrates such as peat, compost, and other bioagents have been successfully used to cultivate different horticulture crops (Agegnehu et al., 2016; Blok et al., 2017; Oustriere et al., 2017; Trupiano et al., 2017). Biochar shows a good response in a potting soil mixture agent as it retains water, supplies nutrients, provides a niche to microbial life, and suppresses diseases (Blok et al., 2017). When biochar was applied with *Bradyrhizobium* inoculums to Lupin (*L. angustifolius* L.), it improved its growth under drought stress conditions (Egamberdieva et al., 2017). Soya bean nodulation increases when biochar is used along with *Rhizobium* bacteria (Ma et al., 2019). When biochar is used as a soil conditioner, it shows better growth and production in broad bean (Egamberdieva et al., 2020), improves maize yield and biomass production (Zhu et al., 2014), increases endophytic bacteria that suppress diseases (Egamberdieva et al., 2020), increases avocado yields (Joseph et al., 2020), increases tomato yields (Priya et al., 2020), and enhances vegetable production (Jia et al., 2012). Despite the positive effect of biochar on plant health, it also has undesirable effects on plant growth. It may be due to high salt content and high pH value and contain phytotoxic compounds that affect the soil enzymes and microbes and, in return, adversely affect plant health. Therefore, the use of biochar as a soil amendment depends on the properties of the biochar and the ratio of the biochar with other composts or substrates. It has been established that biochar must have low salt content and pH if it is to be used in horticulture. Other important factors like water-holding capacity, stability, and nutrient content and the absence of phytotoxic compound must be considered before applying to the soil. Thus, to use biochar as a soil amendment, its production process must be optimized to make it favorable for horticulture crops. Biochar has a low oxygen uptake rate; in consequence of this, a free carbon source is hardly available for microbes; therefore, if anyone wishes to stimulate microbial activity in the soil, an additional source of carbon must be added (Blok et al., 2016). There are many ways through which biochar works on soil, and among them the most probable ones are listed below:

- Improves soil quality by improvising pH
- Increases soil water-holding capacity
- Stimulates activity of beneficial fungi and microbes
- Improves EC and cation exchange capacity
- Retains nutrients
- Sequestrates carbon from the atmosphere-biosphere pool and transfer it to the soil

9.4 Sustainable Agriculture and Biochar

There has been a paradigm shift in the agriculture of developed countries from traditional practices to modern practices, with the rising demands of food for the over-expanding population. It has transfigured the face of agricultural practices, with farmers relying more on high-level inorganic fertilizers and pesticides (Edwards, 2019). The higher inputs of inorganic fertilizers and pesticides along with specialized breed crops have responded well. They have increased yields dramatically, but in due course of time, the soil's inherent fertility has been degraded. The heavy use of chemical fertilizer has created many changes to soil physical and chemical properties.

Moreover, the applied pesticides absorbed by the crops enter into the food chain and get accumulated in the higher consumers to get biologically magnified, resulting in interference in the ecological cycle, causing harmful effects on the environment and arable land and consumer health. Therefore, a sustainable approach could be a practical step to reduce the vulnerability of land to degradation. The concept of agroecology could define the sustainability of agriculture, and the elements of agroecology could establish a relationship between the (Fig. 9.5) application of biochar and agricultural sustainability (FAO, 2018).

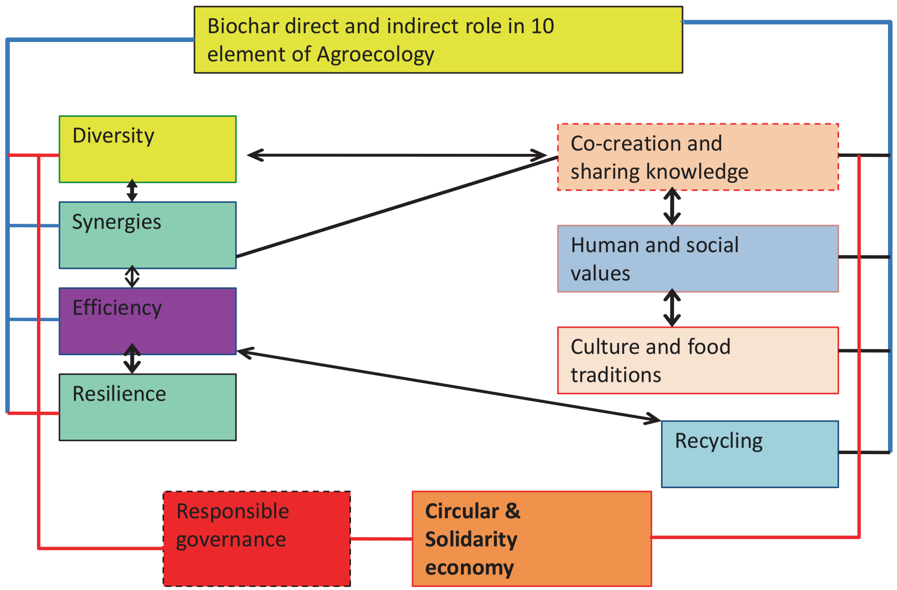

Fig. 9.5 Showing integration of biochar with ten elements: The ten elements of agroecology have been defined by the FAO

Biochar delivers various practical impacts on the environment, and many studies have mentioned the role of biochar in sustainable agriculture (Lehmann & Joseph, 2009; Jyoti Rawat & Sanwal, 2019).

9.5 Conclusions

Biochar is obtained from various biomasses through the thermochemical process by numerous techniques and methods, but all the production techniques or methods are not farmer-friendly. Due to the outrageous cost of setting up a unit for biochar production, the most efficient method conceivably is the TLUD method because this method is user-friendly and portable and has a meagre production cost. Successful application of biochar is an ancient practice; however, its application in horticultural is not a very old practice. Long-term application of biochar would help in the reclamation of contaminated soil, reduce soil toxicity and sequestration of carbon, reduce nutrient leaching, provide a niche for microbes, and assist in the effective management of agri-waste. However, proper dosages based on soil type and specific requirement should be optimized, as an accurate characterization of biochar, and its probable fate in the soil needs extensive research.

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