We are IntechOpen, the world's leading publisher of Open Access books
Built by scientists, for scientists

5,600
Open access books available

138,000
International authors and editors

170M
Downloads

154
Countries delivered to

Our authors are among the
TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Chapter

Biochar: A Sustainable Approach for Improving Plant Growth and Soil Properties

Jyoti Rawat, Jyoti Saxena and Pankaj Sanwal

Abstract

Soil is the most important source and an abode for many nutrients and microflora. Due to rapid depletion of agricultural areas and soil quality by means of ever-increasing population and an excessive addition of chemical fertilizers, a rehabilitated attention is a need of the hour to maintain sustainable approaches in agricultural crop production. Biochar is the solid, carbon-rich material obtained by pyrolysis using different biomasses. It has been widely documented in previous studies that, the crop growth and yield can be increased by using biochar. This chapter exclusively summarizes the properties of biochar, its interaction with soil microflora, and its role in plant growth promotion when added to the soil.

Keywords: biochar, pyrolysis, soil microflora, nutrients, plant growth promotion

1. Introduction

Crop growth and productivity are strongly influenced by various biotic and abiotic stresses such as pests, weeds, drought, high salinity, extreme temperature, etc. and the soil quality [1]. Soil is also contaminated by heavy metals through various human activities [2], which affect plant growth and development and ultimately brings low yielding cropping systems. Mining is one of the important sources of heavy metal contamination in soil [3, 4]. The strength of soil is directly related to nutrient availability. Plants require a number of soil nutrients like nitrogen (N), phosphorus (P), and potassium (K) for their growth, but soil nutrient levels may decrease over time after crop harvesting, as nutrients are not returned to the soil. In India, the soil of many regions is not only deficient in macronutrients like NPK but also in secondary nutrients (e.g. sulfur, calcium, and magnesium) and micronutrients (e.g. boron, zinc, copper, and iron) [5]. Thus, to fulfill the shortage, a large amount of chemical fertilizers is added to the soil; however, only a small percent of water-soluble nutrients are taken up by the plants and the rest are converted into insoluble forms, making continuous application necessary. Finally, the extensive use of chemical fertilizers has led to the deterioration of the environment causing infinite problems. It not only lowers the nutrient composition of the crops but also degrades the soil fertility in the long run [6, 7].

Besides fertilizers, pesticides are also the basic evil for agriculture, and the adverse effects of pesticides on the environment are truly responsible for influencing the microbial properties of soil. High inputs of fertilizers and pesticides and their long persistence in the soil adversely affect the soil microflora, thereby disturbing soil

IntechOpen

health and significantly reducing the total bacterial and fungal biomass [8]. Due to long-term treatment with inorganic fertilizers (N and NPK) and/or organic manures, a shift in structural diversity and dominant bacterial groups in agricultural soils has been recorded by Wu et al. [9]. Biofertilizers, on the other hand, can reenergize the soil by improving the soil fertility and hence can be used as a powerful tool for sustainable agriculture, rendering agro-ecosystems more stress-free. Additionally, the application of organic amendments to soils, from a remedial point of view, has typically been justified by their relatively low cost, which normally requires other forms of disposal (burial in a landfill, incineration, etc.). Soil amendments must possess properties such as high binding capacity and environmental safety and should have no negative effect on the soil structure, soil fertility, or the ecosystem on the whole [10]. The use of biochar has been accepted as a sustainable approach and a promising way to improve soil quality and remove heavy-metal pollutants from the soil [11].

Biochar is a carbon-rich organic material, an organic amendment, and a by-product derived from biomass by pyrolysis under high-temperature and low-oxygen conditions. Biochar is produced through a process called pyrolysis, which basically involves heating of biomass (such as wood, manure, or leaves) in complete or almost complete absence of oxygen, with oil and gas as co-products. However, the quantity of these materials produced depends on the processing conditions. Recently, it has been reported that biochar obtained from the carbonization of organic wastes can be a substitute that not only influences the sequestration of soil carbon but also modifies its physicochemical and biological properties [12, 13].

Biochar has the potential to produce farm-based renewable energy in an eco-friendly way. Specifically, the quality of biochar depends on several factors, such as the type of soil, metal, and the raw material used for carbonization, the pyrolysis conditions, and the amount of biochar applied to the soil [14]. In addition, the biochar amendment to the soil proved to be beneficial to improve soil quality and retain nutrients, thereby enhancing plant growth [15]. Since biochar contains organic matter and nutrients, its addition increased soil pH, electric conductivity (EC), organic carbon (C), total nitrogen (TN), available phosphorus (P), and the cation-exchange capacity (CEC) [16]. Earlier, Verheijen et al. [17] reported that the biochar application affected the toxicity, transport, and fate of various heavy metals in the soil due to improved soil absorption capacity. The presence of plant nutrients and ash in the biochar and its large surface area, porous nature, and the ability to act as a medium for microorganisms have been identified as the main reasons for the improvement in soil properties and increase in the absorption of nutrients by plants in soils treated with biochar [18]. Chan et al. [19] reported that biochar application decreased the tensile strength of soil cores, indicating that the use of biochar can reduce the risk of soil compaction. A lot has already been discussed on the benefits of inoculation of rhizobacteria in soil, but the addition of biochar can also provide more nutrients to the soil, thus benefiting the agricultural crops. The mixing of the plant growth-promoting microorganisms with biochar was referred to as the best combination for growth and yield of French beans by Saxena et al. [20].

Addition of biochar in the soil can be extremely useful to improve the soil quality, as well as to stimulate the plant growth, and thus, biochar can play an important role in developing a sustainable system of agriculture. Several uses and positive effects of biochar amendment have currently been considered as an effective method to reclaim the contaminated soil [21] and to achieve high crop yields without harming the natural environment. The positive influence of biochar on plant growth and soil quality suggests that using biochar is a good way to overcome nutrient deficiency, making it a suitable technique to improve farm-scale nutrient cycles. Therefore, a complete focus is been made to explore the positive effects of biochar amendment on soil stability and plant growth promotion.

2. Biochar production and properties

Biochar is made up of elements such as carbon, hydrogen, sulfur, oxygen, and nitrogen as well as minerals in the ash fraction. It is produced during pyrolysis, a thermal decomposition of biomass in an oxygen-limited environment. Biochar is black, highly porous, and finely grained, with light weight, large surface area and pH, all of which have a positive effect on its application to soil. To address the major concern on quality of agricultural soil degradation, biochar is applied to the soil in order to enhance its quality. Biochar is stabilized biomass, which may be mixed into soil with intentional changes in the properties of the soil's atmosphere to increase crop productivity and to mitigate pollution. The raw material (biomass) used and processing parameters dictate the properties of the biochar.

2.1 Biomass as a raw material

A wide range of organic materials are suitable as feedstock for the production of biochar. Biochar can be produced with raw materials such as grass, cow manure, wood chips, rice husk, wheat straw, cassava rhizome, and other agricultural residues [22, 23]. It was reported that the production of biochar with high nutrients depends on the type of raw material used and pyrolysis conditions [24]. Biochar is produced from the residual biomasses such as crop residues, manure, wood residues, and forests and green wastes using modern pyrolysis technology. Agricultural wastes (bark, straw, husks, seeds, peels, bagasse, sawdust, nutshells, wood shavings, animal beds, corn cobs and corn stalks, etc.), industrial wastes (bagasse, distillers' grain, etc.), and urban/municipal wastes [25, 26] have been extensively used, thus also achieving waste management through its production and use [27].

Feedstocks currently used on a commercial scale include tree bark, wood chips, crop residues (nut shells, straw, and rice hulls), grass, and organic wastes including distillers' grain, bagasse from the sugarcane industry, mill waste, chicken litter, dairy manure, sewage sludge, and paper sludge [28–30]. A 40 wt.% yield of biochar from maize stover was obtained by Peterson et al. [31].

The biomass used for the production of biochar is mainly composed of cellulose, hemicellulose, and lignin polymers [32]. Among these, cellulose has been found to be the main component of most plant-derived biomasses, but lignin is also important in woody biomass.

2.2 Biochar production

Biochar can be manufactured on a small scale using low-cost modified stoves or kilns or through large-scale, cost-intensive production, which utilizes larger pyrolysis plants and higher amounts of feedstocks. Biochar is produced from several biomass feedstocks through pyrolysis as discussed above, generating oil and gases as by-products [33]. The dry waste obtained is simply cut into small pieces to less than 3 cm prior to use. The feedstock is heated either without oxygen or with little oxygen at the temperatures of 350–700°C (662–1292°F). Pyrolysis is generally classified by the temperature and time duration for heating; fast pyrolysis takes place at temperatures above 500°C and typically happens on the order of seconds (heating rates $\geq$ 1000°C/min). This condition maximizes the generation of bio-oil. Slow pyrolysis, on the other hand, usually takes more time, from 30 min to a few hours for the feedstock to fully pyrolyze (heating rates $\leq$ 100°C/min) and at the same time yields more biochar. The temperature range remains 250–500°C [34].

The type of biochar produced depends on two variables: the biomass being used and the temperature and rate of heating. High and low temperatures have an unequivocal effect on char yields. It has been noticed that at low temperature (<550°C), biochar has an amorphous carbon structure with a lower aromaticity than the biochar produced at high temperature [35]. High temperature leads to lower char yield in all pyrolysis reactions [36]. Peng et al. [37] reported the effect of charring duration on the yield of biochar; yield showing a decrease with increasing duration at the same temperature. The pyrolysis process seriously affects the quality of biochar and its potential value to agriculture in terms of agronomic performance or in carbon sequestration. The yield of biochar from slow pyrolysis of biomass has been stated to be in the range of 24–77% [38, 39] (**Figure 1**). The pyrolysis process can be shown as follows:

$$\text{Biomass (Solid)} \rightarrow \text{Biochar} + \text{Liquid or oil (tars, water, etc.)} + \text{Volatile gases } (CO_2, CO, H_2) \quad (1)$$

2.3 Physical, chemical and biological properties of biochar

Biochar is a stable form of carbon and can last for thousands of years in the soil [40]. It is produced for the purpose of addition to soil as a means of sequestering carbon and improving soil quality. The conditions of pyrolysis and the materials used can significantly affect the properties of biochar. The physical properties of biochar contribute to its function as a tool for managing the environment. It has been reported that when biochar is used as a soil amendment, it stimulates soil fertility and improves soil quality by increasing soil pH, increasing the ability to retain moisture, attracting more useful fungi and other microbes, improving the ability of

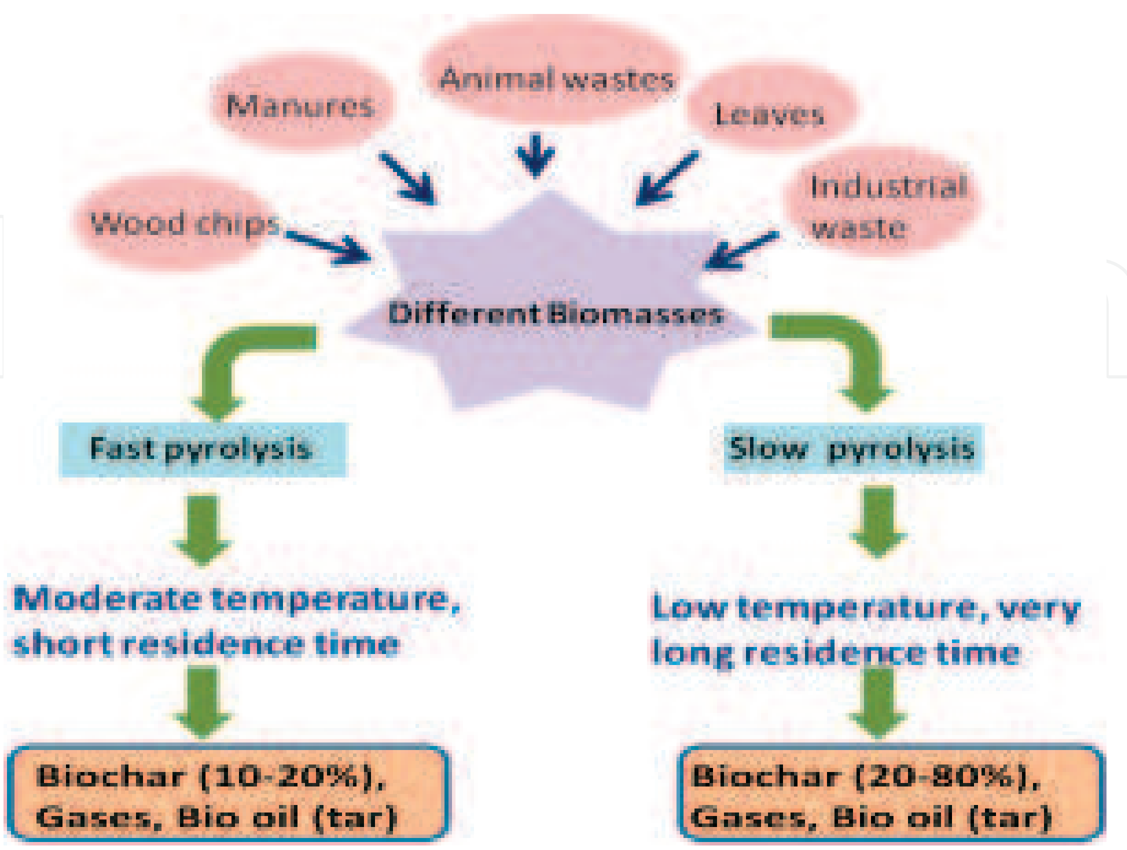

Figure 1.
Biochar production from different biomasses.

cation exchange, and preserving the nutrients in the soil [41]. Biochar reduces soil density and soil hardening, increases soil aeration and cation-exchange capacity, and changes the soil structure and consistency through the changes in physical and chemical properties. It also helps to reclaim degraded soils. It has shown a greater ability to adsorb cations per unit carbon as compared to other soil organic matters because of its greater surface area, negative surface charge, and charge density [42], thereby offering the possibility of improving yields [43]. Samples with a sufficient amount of stable carbon can be added to the soil to be sequestered; a high sorption surface of biochar can characterize it as a soil additive, competent of halting risk elements in soil.

The physical characteristics of biochar are directly and indirectly related to how they affect soil systems. Soils have their own physical properties depending on the nature of mineral and organic matter, their relative amounts, and how minerals and organic matter are related. When biochar is present in the soil mixture, its contribution to the physical nature of the system is significant, affecting the depth, texture, structure, porosity, and consistency by changing the surface area, pore and particle-size distribution, density, and packing [44]. The influence of biochar on physical properties of soil directly affects the growth of plants, since the depth of penetration and accessibility of air and water in the root zone is determined mainly by the physical composition of the soil horizons. This affects the soil's response to water, its aggregation, and work ability in soil preparation, dynamics, and permeability when swelling, as well as the ability to retain cations and response to changes at ambient temperature. The smaller the pores on biochar, the longer they can retain capillary soil water. The addition of biochar can reduce the effects of drought on crop productivity in drought-affected areas due to its moisture-retention capacity. It has been shown that it eliminates soil constraints that limit the growth of plants, and neutralizes acidic soil because of its basic nature [45]. Carbon dioxide and oxygen occupy air-filled spaces on the pores of biochar or can be chemosorbed on the surface. As biochar can contain nutrients, microorganisms, and syngases, it can also retain fertilizers in the soil longer than other soils and prevent it from leaching into water sources such as rivers and lakes.

As far as its chemical properties are concerned, biochar reduces soil acidity by increasing the pH (also called the liming effect) and helps the soil to retain nutrients and fertilizers [46]. The application of biochar improves soil fertility through two mechanisms: adding nutrients to the soil (such as K, to a limited extent P, and many micronutrients) or retaining nutrients from other sources, including nutrients from the soil itself. However, the main advantage is to retain nutrients from other sources. In most cases, the addition of biochar only has a net positive effect on the growth of crops if nutrients from other sources, such as inorganic or organic fertilizers, are used. Biochar increases the availability of C, N, Ca, Mg, K, and P to plants, because biochar absorbs and slowly releases fertilizers [47]. It also helps to prevent fertilizer drainage and leaching by allowing less fertilizer use and reducing agricultural pollution in the surrounding environment [48]. Biochar alleviates the impact of hazardous pesticides and complex nitrogen fertilizers from the soil, thus reducing the impact on the local environment.

Good healthy soil should include a wide and balanced variety of life forms, including bacteria, fungi, protozoa, nematodes, arthropods, and earthworms. Recently, biochar has been reported to increase the microbial respiration of the soil by creating space for soil microbes [49], and in turn the soil biodiversity and soil density increased. Biochar also served as a habitat for extra-radical fungal hyphae that sporulated in micropores due to lower competition from saprophytes and therefore served as an inoculum for arbuscular mycorrhizal fungi [50]. It is believed that biochar has a long average dwelling time in soil, ranging from 1000 to 10,000 years, with an average of 5000 years [51–53]. However, its recalcitrance and physical nature present significant impediment to the evaluation of long-term stability [43]. The commercially available soil microbes which can be used for inoculation include *Azospirillum* sp., *Azotobacter* sp., *Bacillus thuringiensis*, *B. megaterium*, *Glomus fasciculatum*, *G. mosseae*, *Pseudomonas fluorescens*, *Rhizobium* sp., and *Trichoderma viride* [54].

3. Biochar as a soil amendment

The issues as food security, declining soil fertility, climate change, and profitability are the driving forces behind the introduction of new technologies or new farming systems. The amendment of soils for their remediation aims at reducing the risk of pollutant transfer to waters or receptor organisms in proximity. The organic material such as biochar may serve as a popular choice for this purpose because its source is biological and it may be directly applied to soils with little pretreatment [55]. There are two aspects which make biochar amendment superior to other organic materials: the first is the high stability against decay, so that it can remain in soil for longer times providing long-term benefits to soil and the second is having more capability to retain the nutrients. Biochar amendment improves soil quality by increasing soil pH, moisture-holding capacity, cation-exchange capacity, and microbial flora [56].

The addition of biochar to the soil has shown the increase in availability of basic cations as well as in concentrations of phosphorus and total nitrogen [57, 58]. Typically, alkaline pH and mineral constituents of biochar (ash content, including N, P, K, and trace elements) can provide important agronomic benefits to many soils, at least in the short to medium term. When biochar with a higher pH value was applied to the soil, the amended soil generally became less acidic [59]. Acidic biochar could also increase soil pH when used in soil with a lower pH value. The pH of biochar, similar to the other properties, is influenced by the type of feedstock, production temperature, and production duration.

Another valuable property of biochar is suppression of emissions of greenhouse gases in soil. It has also been demonstrated by Zhang et al. [60] that the emissions of methane and nitrous oxide were reduced from agricultural soils, which may have additional climate mitigation effects, since these are potent greenhouse gases. Spokas et al. [61] reported reduced carbon dioxide production by addition of different concentrations of biochar ranging from 2 to 60% (w/w), suppressed nitrous oxide production at levels higher than 20% (w/w), and ambient methane oxidation at all levels over unamended soil.

Several studies have shown the control of pathogens by the use of biochar in agricultural soil. Bonanomi et al. [62] reported that biochar is effective against both air-borne (e.g. *Botrytis cinerea* and different species of powdery mildew) and soil-borne pathogens (e.g. *Rhizoctonia solani* and species of *Fusarium* and *Phytophthora*). The application of the biochar derived from citrus wood was capable of controlling air-borne gray mold, *Botrytis cinerea* on *Lycopersicon esculentum*, *Capsicum annuum* and *Fragaria × ananassa*. Although there is a shortage of published data on the effects of biochar on soil-borne pathogens, evidence given by Elmer et al. [63] has shown that the control of certain pathogens may be possible. The addition of biochar in 0.32, 1.60, and 3.20% (w/w) to asparagus soils infested with *Fusarium* has augmented the biomass of asparagus plants and reduced *Fusarium* root rot disease [63]. Similarly, *Fusarium* root rot disease in asparagus was also reduced by biochar inoculated with mycorrhizal fungi [64]. A study of suppression of bacterial wilt in tomatoes showed that biochar obtained from municipal organic waste reduced the incidence of the disease in *Ralstonia solanacearum* infested soil [65]. Ogawa [66] advocated the use of biochars and biochar amended composts for controlling the diseases caused by bacteria and fungi in soil. The disease suppression mechanism has been attributed to the presence of calcium compounds, as well as improvements in the physical, chemical, and biological characteristics of the soil.

The prevention of 'diffuse water pollution' through ammonium sorption or the mediation of the dynamics of a soil solution containing nitrate, phosphorus, and other nutrients has been extensively studied. The application of biochar to soil can influence a wide range of soil constraints such as high availability of Al [67], soil structure and nutrient availability [24], bioavailability of organic [68] and inorganic pollutants [69], cation-exchange capacity (CEC), and retention of nutrients [70, 71]. Biochar can also adsorb pesticides, nutrients, and minerals in the soil, preventing the movement of these chemicals into surface water or groundwater and the subsequent degradation of these waters from agricultural activity.

Xie et al. [72] reported that biochar amendment enhanced soil fertility and crop production, particularly in soils with low nutrients. However, in soils with high fertility, no noticeable increase in production was noticed, and some studies even reported inhibition of plant growth. The observations of Taghizadeh-Toosi et al. [73] indicated that ammonia adsorbed by biochar could be later released to the soil. Saarnio et al. [74] showed that biochar application along with fertilizers can lead to better plant growth, but sometimes a negative effect was also observed without fertilization due to reduced bio-availability through sorption of nitrogen. It has been shown that application of biochar in the soil has a positive to neutral and even negative impact on crop production. Hence, it is crucial that the mechanisms for action of biochar in the soil be understood before its application.

The consequence of biochar addition on plant productivity depends on the amount added. Recommended application rates for any soil amendment should be based on extensive field testing. At present, insufficient data are available for obtaining general recommendations. In addition, biochar materials can vary greatly in their characteristics, so the nature of the particular biochar material (e.g. pH and ash content) also influences the application rate. Several studies have reported a positive effect of using biochar on crop yields with rates of 5–50 tonnes per hectare with appropriate nutrient management. The experiments conducted by Rondon et al. [75] resulted in a decrease in crop yield in a pot experiment with nutrient deficient soil amended with biochar at the rate of 165 tonnes per hectare. An experiment conducted in the United States showed that peanut hull and pine chip biochar, applied to 11 and 22 tonnes per hectare, could reduce corn yields below those obtained in the control plots with standard fertilizer management [76]. Thus, the control of the rate of application of biochar is necessary to prevent the negative impact of biochar.

4. Stimulation of soil microflora and plant growth

There are several reports which show that biochar has the capability to stimulate the soil microflora, which results in greater accumulation of carbon in soil. Besides adsorbing organic substances, nutrients, and gases, biochars are likely to offer a habitat for bacteria, actinomycetes and fungi [64]. It has been suggested that faster heating of biomass (fast pyrolysis) will lead to the formation of biochar with fewer microorganisms, smaller pore size, and more liquid and gas components [77]. The enhancement of water retention after biochar application in soil has been well established [78], and this may affect the soil microbial populations. Biochar provides a suitable habitat for a large and diverse group of soil microorganisms, although the interaction of biochar with soil microorganisms is a complex phenomenon. Many studies reported that addition of biochar along with phosphate solubilizing fungal strains promoted growth and yield of *Vigna radiata* and *Glycine max* plants, with better performances than control or those observed when the strains and biochar are used separately [20, 79, 80].

The use of biochar increased mycorrhizal growth in clover bioassay plants by providing the suitable conditions for colonization of plant roots [81]. Warnock et al. [82] summarized four mechanisms by which biochar can affect functioning of mycorrhizal fungi: (i) changes in the physical and chemical properties of soil, (ii) indirect effects on mycorrhizae through exposure to other soil microbes, (iii) plant-fungus signaling interference and detoxification of toxic chemicals on biochar, and (iv) providing shelter from mushroom browsers. Carrots and legumes grown on steep slopes and in soils with less than 5.2 pH showed significantly improved growth by the addition of biochar [83]. It was found that biochar increased the biological N_2 fixation (BNF) of *Phaseolus vulgaris* [75] mainly due to greater availability of micronutrients after application of biochar. Lehmann et al. [58] reported that biochar reduced leaching of NH_4^+ by supporting it in the surface soil where it was available for plant uptake. Mycorrhizal fungi were often included in crop management strategies as they were widely used as supplements for soil inoculum [84]. When using both biochar and mycorrhizal fungi in accordance with management practices, it is obviously possible to use potential synergism that can positively affect soil quality. The fungal hyphae and bacteria that colonize the biochar particles (or other porous materials) may be protected from soil predators such as mites, Collembola and larger (>16 μm in diameter) protozoans and nematodes [85–87].

Biochar can increase the value of non-harvested agricultural products [88] and promote the plant growth [58, 89]. A single application of 20 t ha^{-1} biochar to a Colombian savanna soil resulted in an increase in maize yield by 28–140% as compared with the unamended control in the 2nd to 4th years after application [90]. With the addition of biochar at the rate of 90 g kg^{-1} to tropical, low-fertile ferralsol, not only the proportion of N fixed by bean plants (*Phaseolus vulgaris*) increased from 50% (without biochar) to 72%, but also the production of biomass and bean yield were improved significantly [75]. When biochar was applied to the soil, a higher grain yield of upland rice (*Oryza sativa*) was obtained in northern Laos sites with low P availability [91, 92]. Many of these effects are interrelated and may act synergistically to improve crop productivity. Often there has been a reported increase in yields, which is directly related to the addition of biochar as compared to the control (without biochar) [58]. However, in some cases, growth was found to be depressed [93].

The direct beneficial effects of biochar addition for the availability of nutrients are largely due to the higher content of potassium, phosphorus, and zinc availability and, to a lesser extent, calcium and copper [58]. Few studies have examined the potential for amending biochar in soil to impact plant resistance to pathogens. With reference to soil pathogens principally concerned with the effect of AM fungal inoculations on asparagus tolerance to the soil borne root rot pathogen *Fusarium*, Matsubara et al. [94] demonstrated that charcoal amendments had a suppressive effect on pathogens. One more study that supported these earlier findings stated that biochar made from ground hardwood added to asparagus field soil led to a decrease in root lesions caused by *Fusarium oxysporum*, *F. asparagi,* and *F. proliferatum* compared to the non-amended control [95]. Biochar reduces the need for fertilizer, which results in reduction in emissions from fertilizer production, and turning the agricultural waste into biochar also reduces the level of methane (another potent greenhouse gas) caused by the natural decomposition of waste.

5. Mixing biochar with other amendments

Mixing biochar with other soil amendments such as manure, compost, or lime before soil application can improve efficiency by reducing the number of field operations required. Since biochar has been shown to sorb nutrients and protect them from leaching [70, 96], mixing of biochar may improve the efficiency of manure and other amendments. However, Kammann et al. [97] acknowledged in their recent review that very few studies that directly combined organic amendments with biochars were available. They found that co-composted biochars had a remarkable plant growth-promoting effect as compared to biochars when used pure, but no-systematic studies have been done to understand the interactive effects of biochars with non-pyrogenic organic amendments (NPOAs). Biochar can also be mixed with liquid manures and used as slurry. Additionally, combined biochar and compost applications have numerous advantages over mixing of biochar or compost with soil separately. These benefits, according to Liu et al. [98], include more efficient use of nutrients, biological activation of biochar, an enhanced supply of plant-available nutrients by biological nitrogen fixation, reduction of nutrient leaching, and the contribution of combined nutrients in comparison to a single application of compost and biochar. Diminutive biochars are most likely best suited for this type of application. Biochar was also mixed with manure in ponds and potentially reduced losses of nitrogen gas were recorded same as when it was applied to soil [99, 100].

6. Conclusion

The problem of the depletion of agricultural land as a result of the pressure caused by the ever-growing population necessitated the sustainable practice of crop production. It was suggested to use biochar as a means of remediating contaminated agricultural soil, improving soil fertility by reducing the acidity, and increasing the availability of nutrients. Thus, addition of biochar to the soil can be one of the best practices to overcome any biotic stress in soil and to increase the crop productivity. The positive effects of biochar on the interactions between soil-plant-water caused better photosynthetic performance and improved nitrogen and water use efficiency. Hence, it can be concluded by this comprehensive review that biochar has the potential to improve the properties of soil, microbial abundance, biological nitrogen fixation, and plant growth. Therefore, it is recommended to use biochar as a soil amendment for long-term carbon sink restoration.

Author details

Jyoti Rawat[1], Jyoti Saxena[2*] and Pankaj Sanwal[2]

1 Department of Biotechnology, Kumaun University, Bhimtal Campus, Nainital, India

2 Biochemical Engineering Department, B.T. Kumaon Institute of Technology, Dwarahat, India

*Address all correspondence to: saxenajyoti30@gmail.com

IntechOpen

© 2019 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] Thalmann M, Santelia D. Starch as a determinant of plant fitness under abiotic stress. The New Phytologist. 2017;**214**(3):943-951

[2] Moon DH, Park JW, Chang YY, Ok YS, Lee SS, Ahmad M. Immobilization of lead in contaminated firing range soil using biochar. Environmental Science and Pollution Research. 2013;**20**:8464-8471

[3] Al-Farraj AS, Usman ARA, Al Otaibi SHM. Assessment of heavy metals contamination in soils surrounding a gold mine: Comparison of two digestion methods. Chemistry and Ecology. 2013;**29**:329-339

[4] Noman A, Aqeel M. miRNA-based heavy metal homeostasis and plant growth. Environmental Science and Pollution Research. 2017;**24**(11):3-10

[5] Pathak H. Trend of fertility status of Indian soils. Current Advances in Agricultural Sciences. 2010;**2**(1):10-12

[6] Hariprasad NV, Dayananda HS. Environmental impact due to agricultural runoff containing heavy metals—A review. International Journal of Scientific and Research Publications. 2013;**3**(5):1-6

[7] Yargholi B, Azarneshan S. Long-term effects of pesticides and chemical fertilizers usage on some soil properties and accumulation of heavy metals in the soil (case study of Moghan plain's (Iran) irrigation and drainage network). International Journal of Agriculture and Crop Sciences. 2014;**7**:518-523

[8] Prashar P, Shah S. Impact of fertilizers and pesticides on soil microflora in agriculture sustainable agriculture reviews. Sustainable Agriculture Reviews. 2016;**19**:331-362

[9] Wu F, Gai Y, Jiao Z, Liu Y, Ma X, An L, et al. The community structure of microbial in arable soil under different long-term fertilization regimes in the Loess Plateau of China. African Journal of Microbiology Research. 2012;**6**:6152-6164

[10] Paz-Ferreiro J, Lu H, Fu S, Méndez A, Gascó G. Use of phytoremediation and biochar to remediate heavy metal polluted soils: A review. Solid Earth Discussions. 2013;**5**:2155-2179

[11] Lahori AH, Zhanyu G, Zhang Z, li R, Mahar A, Awasthi M, et al. Use of biochar as an amendment for remediation of heavy metal-contaminated soils: Prospects and challenges. Pedosphere. 2017;**27**:991-1014

[12] García AC, de Souza LGA, Pereira MG, Castro RN, García-Mina JM, Zonta E, et al. Structure-property-function relationship in humic substances to explain the biological activity in plants. Scientific Reports. 2016;**6**:20798. DOI: 10.1038/srep20798

[13] Zhang R, Zhang Y, Song L, Song X, Hanninen H, Wu J. Biochar enhances nut quality of *Torreya grandis* and soil fertility under simulated nitrogen deposition. Forest Ecology and Management. 2017;**391**:321-329

[14] Debela F, Thring RW, Arocena JM. Immobilization of heavy metals by co-pyrolysis of contaminated soil with woody biomass. Water, Air, and Soil Pollution. 2012;**223**:1161-1170

[15] Bonanomi G, Ippolito F, Cesarano G, Nanni B, Lombardi N, Rita A, et al. Biochar as plant growth promoter: Better off alone or mixed with organic amendments? Frontiers in Plant Science. 2017;**8**:1570. DOI: 10.3389/fpls.2017.01570

[16] Dume B, Mosissa T, Nebiyu A. Effect of biochar on soil properties

and lead (Pb) availability in a military camp in South West Ethiopia. African Journal of Environmental Science and Technology. 2016;**10**(3):77-85

[17] Verheijen F, Jeffery S, Bastos AC, van der Velde M, Diafas I. Biochar Application to Soils—A Critical Scientific Review of Effects on Soil Properties, Processes and Functions. Luxemburg: EUR 24099 EN Office for the Official Publications of the European Communities; 2009. p. 149

[18] Nigussie A, Kissi E, Misganaw M, Ambaw G. Effect of biochar application on soil properties and nutrient uptake of Lettuces (*Lactuca sativa*) grown in chromium polluted soils. American-Eurasian Journal of Agriculture and Environmental Science. 2012;**12**(3):369-376

[19] Chan K, Van Zwieten L, Meszaros I, Downie A, Joseph S. Using poultry litter biochars as soil amendments. Australian Journal of Soil Research. 2008;**46**(5):437-444

[20] Saxena J, Rana G, Pandey M. Impact of addition of biochar along with *Bacillus* sp. on growth and yield of French beans. Scientia Horticulturae. 2013;**162**:351-356

[21] Placek A, Grobelak A, Kacprzak M. Improving the phytoremediation of heavy metals contaminated soil by use of sewage sludge. International Journal of Phytoremediation. 2016;**18**(6):605-618

[22] Ronsse F, van Hecke S, Dickinson D, Prins W. Production and characterization of slow pyrolysis biochar: Influence of feedstock type and pyrolysis conditions. GCB Bioenergy. 2013;**5**:104-115

[23] Kiran YK, Barkat A, Xiao-qiang CUI, Ying F, Feng-shan P, Lin T, et al. Cow manure and cow manure-derived biochar application as a soil amendment for reducing cadmium availability and accumulation by *Brassica chinensis* L. in acidic red soil. Journal of Integrative Agriculture. 2017;**16**(3):725-734

[24] Chan KY, Van Zwieten L, Meszaros I, Downie A, Joseph S. Agronomic values of greenwaste biochar as a soil amendment. Australian Journal of Soil Research. 2007;**45**:629-634

[25] Novotny EH, Maia CMB de F, Carvalho MT de M, Madari BE. Biochar: Pyrogenic carbon for agricultural use—A critical review. Revista Brasileira de Ciência do Solo. 2015;**39**(2):321-344

[26] Kameyama K, Miyamoto T, Iwata Y, Shiono T. Influences of feedstock and pyrolysis temperature on the nitrate adsorption of biochar. Soil Science and Plant Nutrition. 2016;**62**(2):180-184

[27] Woolf D, Amonette J, Street-Perrott F, Lehmann J, Joseph S. Sustainable biochar to mitigate global climate change. Nature Communications. 2010;**1**:1-9

[28] Tumuluru JS, Sokhansanj S, Hess JR, Wright CT, Boardman RD. A review on biomass torrefaction process and product properties for energy applications. Industrial Biotechnology. 2011;**7**:384-402

[29] Sohi S, Loez-Capel S, Krull E, Bol R. Biochar's roles in soil and climate change: A review of research needs. CSIRO Land and Water Science Report. 2009;**5**(09):17-31

[30] Reddy KR. Characteristics and applications of biochar for environmental remediation: A review. Critical Reviews in Environmental Science and Technology. 2015;**45**:939-969

[31] Peterson SC, Jackson MA, Kim S, Palmquist DE. Increasing biochar surface area: Optimization of ball milling parameters. Powder Technology. 2012;**228**:115-120

[32] Sullivan AL, Ball R. Thermal decomposition and combustion chemistry of cellulosic biomass. Atmospheric Environment. 2012;**47**:133-141

[33] Zhu L, Lei H, Zhang Y, Zhang X, Bu Q, Wei Y, et al. A review of biochar derived from pyrolysis and its application in biofuel production. SF Journal of Material and Chemical Engineering. 2018;**1**(1):1007

[34] Brown TR, Wright MM, Brown RC. Estimating profitability of two biochar production scenarios: Slow pyrolysis vs fast pyrolysis. Biofuels, Bioproducts and Biorefining. 2011;**5**(1):54-68

[35] Joseph SD, Camps-Arbestain M, Lin Y, Munroe P, Chia CH, Hook J, et al. An investigation into the reactions of biochar in soil. Australian Journal of Soil Research. 2010;**48**:501-515

[36] Antal MJ, Grønli M. The art, science, and technology of charcoal production. Industrial and Engineering Chemistry Research. 2003;**42**(8):1619-1640

[37] Peng X, Ye LL, Wang CH, Bo S. Temperature and duration dependent rice straw derived biochar: Characteristics and its effects on soil properties of an Ultisol in southern China. Soil and Tillage Research. 2011;**112**(2):159-166

[38] Dutta B. Assessment of pyrolysis techniques of lignocellulosic biomass for biochar production [dissertation—master's thesis]. McGill University; 2010

[39] Stoyle A. Biochar production for carbon sequestration [master's thesis]. Shanghai Jiao Tong University; 2011

[40] Shenbagavalli S, Mahimairaja S. Production and characterization of biochar from different biological wastes. International Journal of Plant, Animal and Environmental Sciences. 2012;**2**(1):197-201

[41] Ajema L. Effects of biochar application on beneficial soil organism review. International Journal of Research Studies in Science, Engineering and Technology. 2018;**5**(5):9-18

[42] Liang B, Lehmann J, Solomon D, Kinyangi J, Grossman J, O"Neill B, et al. Black carbon increases cation exchange capacity in soils. Soil Science Society of America Journal. 2006;**70**:1719-1730

[43] Lehmann J. Bio-energy in the black. Frontiers in Ecology and the Environment. 2007;**5**(7):381-387

[44] Blanco-Canqui H. Biochar and soil physical properties. Soil Science Society of America Journal. 2017;**81**:687-711

[45] Hammes K, Schmidt MWI. Changes in biochar in soils. In: Lehmann M, Joseph S, editors. Biochar for Environmental Management Science and Technology. London: Earthscan; 2009. pp. 169-182

[46] Lehmann J, Gaunt J, Rondon M. Biochar sequestration in the terrestrial ecosystem—A review. Mitigation and Adaptation Strategies for Global Change. 2006;**11**:403-427

[47] DeLuca TH, Gundale MJ, MacKenzie MD, Jones DL. Biochar effects on soil nutrient transformation. In: Lehmann J, Joseph S, editors. Biochar for Environmental Management: Science and Technology. 2nd ed. Routledge; 2015. pp. 421-454

[48] Cao Y, Gao Y, Qi Y, Li J. Biochar-enhanced composts reduce the potential leaching of nutrients and heavy metals and suppress plant-parasitic nematodes in excessively fertilized cucumber soils. Environmental Science and Pollution Research International. 2018;**25**(8):7589-7599

[49] Slapakova B, Jerabkova V, Tejnecky DO. The biochar effect on soil respiration and nitrification. Plant, Soil and Environment. 2018;**64**(3):114-119

[50] Saito M, Marumoto T. Inoculation with arbuscular mycorrhizal fungi: The status quo in Japan and the future prospects. Plant and Soil. 2002;**244**:273-279

[51] Skjemstad JO, Janik LJ, Taylor JA. Non-living soil organic matter: What do we know about it? Australian Journal of Experimental Agriculture. 1998;**38**:667-680

[52] Swift RS. Sequestration of carbon by soil. Soil Science. 2001;**166**:858-871

[53] Krull ES, Skjemstad J, Graetz D, Grice K, Dunning W, Cook G, et al. 13C-depleted charcoal from C4 grasses and the role of occluded carbon in phytoliths. Organic Geochemistry. 2003;**34**:1337-1352

[54] Hazarika BN, Ansari S. Biofertilizers in fruit crops—A review. Agricultural Reviews. 2007;**28**(1):69-74

[55] Beesley L, Moreno-Jiménez E, Gomez-Eyles JL, Harris E, Robinson B, Sizmur T. A review of biochars' potential role in the remediation, revegetation and restoration of contaminated soils. Environmental Pollution. 2011;**159**:3269-3282

[56] Mensah AK, Frimpong KA. Biochar and/or compost applications improve soil properties, growth, and yield of maize grown in acidic rainforest and coastal savannah soils in Ghana. International Journal of Agronomy. 2018:1-8. DOI: 10.1155/2018/6837404

[57] Glaser B, Lehmann J, Zech W. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal: A review. Biology and Fertility of Soils. 2002;**35**:219-230

[58] Lehmann J, da Silva JP Jr, Steiner C, Nehls T, Zech W, Glaser B. Nutrient availability and leaching in an archaeological anthrosol and a ferrasol of the Central Amazon basin: Fertilizer, manure, and charcoal amendments. Plant and Soil. 2003;**249**:343-357

[59] Yuan J, Xu R, Zhang H. The forms of alkalis in the biochar produced from crop residues at different temperatures. Bioresource Technology. 2011;**102**:3488-3497

[60] Zhang A, Cui L, Pan G, Li L, Hussain Q , Zhang X, et al. Effect of biochar amendment on yield and methane and nitrous oxide emissions from a rice paddy from Tai Lake plain, China. Agriculture, Ecosystems and Environment. 2010;**139**(4):469-475

[61] Spokas KA, Koskinen WC, Baker JM, Reicosky DC. Impacts of woodchip biochar additions on greenhouse gas production and sorption/degradation of two herbicides in a minnesota soil. Chemosphere. 2009;**77**:574-581

[62] Bonanomi G, Ippolito F, Scala F. A "black" future for plant pathology? Biochar As a new soil amendment for controlling plant diseases. Journal of Plant Pathology. 2015;**97**(2):223-234

[63] Elmer W, White JC, Pignatello JJ. Impact of biochar addition to soil on the bioavailability of chemicals important in agriculture. Report. New Haven: University of Connecticut; 2010

[64] Thies JE, Rillig M. Characteristics of biochar: Biological properties. In: Lehmann M, Joseph S, editors. Biochar for Environmental Management Science and Technology. London: Earthscan; 2009. pp. 85-105

[65] Nerome M, Toyota K, Islam TM, Nishimima T, Matsuoka T, Sato K, et al. Suppression of bacterial wilt of tomato by incorporation of municipal biowaste

charcoal into soil. Soil Microorganisms. 2005;**59**(1):9-14

[66] Ogawa M. Charcoal use in agriculture in Japan. Keynote address, 1st Asia Pacific Biochar Conference, May 17-20, 2009, Gold Coast, Australia

[67] van Zwieten L, Kimber S, Downie A, Morris S, Petty S, Rust J, et al. A glasshouse study on the interaction of low mineral ash biochar with nitrogen in a sandy soil. Australian Journal of Soil Research. 2010;**48**:569-576

[68] Yu XY, Ying GG, Kookana RS. Reduced plant uptake of pesticides with biochar additions to soil. Chemosphere. 2009;**76**:665-671

[69] Hua L, Wu WX, Liu YX, McBride M, Chen YX. Reduction of nitrogen loss and Cu and Zn mobility during sludge composting with bamboo charcoal amendment. Environmental Science and Pollution Research International. 2009;**16**:1-9

[70] Major J, Lehmann J, Rondon M, Goodale C. Fate of soil-applied black carbon: Downward migration, leaching and soil respiration. Global Change Biology. 2010;**16**(4):1366-1379

[71] Singh PB, Hatton JB, Singh B, Cowie LA, Kathuria A. Influence of biochars on nitrous oxide emission and nitrogen leaching from two contrasting soils. Journal of Environmental Quality. 2010;**39**:1224-1235

[72] Xie Z, Xu Y, Liu G, Liu Q , Zhu J, Tu C, et al. Impact of biochar application on nitrogen nutrition of rice, greenhouse-gas emissions and soil organic carbon dynamics in two paddy soils of China. Plant and Soil. 2013;**370**(1-2):527-540

[73] Taghizadeh-Toosi A, Clough TJ, Sherlock RR, Condron LM. Biochar adsorbed ammonia is bioavailable. Plant and Soil. 2012;**350**:57-69

[74] Saarnio S, Heimonen K, Kettunen R. Biochar addition indirectly affects N_2O emissions via soil moisture and plant N uptake. Soil Biology and Biochemistry. 2013;**58**:99-106

[75] Rondon M, Lehmann J, Ramírez J, Hurtado M. Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with bio-char additions. Biology and Fertility of Soils. 2007;**43**:699-708

[76] Gaskin JW, Speir RA, Harris K, Das KC, Lee RD, Morris LA, et al. Effect of peanut hull and pine chip biochar on soil nutrients, corn nutrient status, and yield. Agronomy Journal. 2010;**102**:623-633

[77] Nartey OD, Zhao B. Biochar preparation, characterization, and adsorptive capacity and its effect on bioavailability of contaminants: An overview. Advances in Materials Science and Engineering. 2014;**2014**(715398). p. 12. Available from: http://dx.doi.org/10.1155/2014/715398

[78] Busscher WJ, Novak JM, Evans DE, Watts DW, Niandou MAS, Ahmedna M. Influence of pecan biochar on physical properties of a Norfolk loamy sand. Soil Science. 2010;**175**:10-14

[79] Saxena J, Rawat J, Sanwal P. Enhancement of growth and yield of *glycine max* plants with inoculation of phosphate solubilizing fungus *Aspergillus niger* K7 and biochar amendment in soil. Communications in Soil Science and Plant Analysis. 2016;**47**(20):2334-2347

[80] Saxena J, Rawat J, Kumar R. Conversion of biomass waste into biochar and the effect on mung bean crop production. Clean—Soil, Air, Water. 2017;**45**(7):1501020 (1-9)

[81] Solaiman ZM, Blackwell P, Abbott LK, Storer P. Direct and residual effect of biochar application on mycorrhizal

root colonisation, growth and nutrition of wheat. Australian Journal of Soil Research. 2010;**48**:546-554

[82] Warnock DD, Lehmann J, Kuyper TW, Rillig MC. Mycorrhizal responses to biochar in soil—Concepts and mechanisms. Plant and Soil. 2007;**300**:9-20

[83] Rondon M, Ramirez A, Hurtado M. Charcoal Additions to High Fertility Ditches Enhance Yields and Qvuality of Cash Crops in Andean Hillsides of Columbia (CIAT Annual Report 2004). Cali, Colombia; 2004

[84] Schwartz MW, Hoeksema JD, Gehring CA, Johnson NC, Klironomos JN, Abbott LK, et al. The promise and the potential consequences of the global transport of mycorrhizal fungal inoculum. Ecology Letters. 2006;**9**:501-515

[85] Saito M. Charcoal as a micro habitat for VA mycorrhizal fungi, and its practical application. Agriculture, Ecosystems and Environment. 1990;**29**:341-344

[86] Pietikainen J, Kiikkila O, Fritze H. Charcoal as a habitat for microbes and its effect on the microbial community of the underlying humus. Oikos. 2000;**89**:231-242

[87] Ezawa T, Yamamoto K, Yoshida S. Enhancement of the effectiveness of indigenous arbuscular mycorrhizal fungi by inorganic soil amendments. Soil Science and Plant Nutrition. 2002;**48**:897-900

[88] Major J, Steiner C, Ditommaso A, Falcão NP, Lehmann J. Weed composition and cover after three years of soil fertility management in the central Brazilian Amazon: Compost, fertilizer, manure and charcoal applications. Weed Biology and Management. 2005;**5**:69-76

[89] Oguntunde PG, Fosu M, Ajayi AE, van de Giesen N. Effects of charcoal production on maize yield, chemical properties and texture of soil. Biology and Fertility of Soils. 2004;**39**:295-299

[90] Major J, Rondon M, Molina D, Riha SJ, Lehmann J. Maize yield and nutrition during four years after biochar application to a Colombian savanna oxisol. Plant and Soil. 2010;**333**:117-128

[91] Asai H, Samson BK, Stephan HM, Songyikhangsuthor K, Homma K, Kiyono Y, et al. Biochar amendment techniques for upland rice production in Northern Laos: 1. Soil physical properties, leaf SPAD and grain yield. Field Crops Research. 2009;**111**(1-2):81-84

[92] Silber A, Levkovitch I, Graber ER. pH-dependent mineral release and surface properties of cornstraw biochar: Agronomic implications. Environmental Science and Technology. 2010;**44**:9318-9323

[93] Mikan CJ, Abrams MD. Altered forest composition and soil properties of historic charcoal hearths in southeastern Pennsylvania. Canadian Journal of Forest Research. 1995;**25**:687-696

[94] Matsubara Y, Hasegawa N, Fukui H. Incidence of *Fusarium* root rot in asparagus seedlings infected with arbuscular mycorrhizal fungus as affected by several soil amendments. Journal of the Japanese Society For Horticultural Science. 2002;**71**:370-374

[95] Elmer WH, Pignatello JJ. Effect of biochar amendments on mycorrhizal associations and *Fusarium* crown and root rot of asparagus in replant soils. Plant Disease. 2011;**95**:960-966

[96] Novak JM, Lima I, Gaskin JW, Steiner C, Das KC, Ahmedna M, et al. Characterization of designer biochar produced at different temperatures and their effects on a loamy sand. Annals of Environmental Science. 2009;**3**:195-206

[97] Kammann C, Glaser B, Schmidt HP. Combining biochar and organic amendments. In: Shackley S, Ruysschaert G, Zwart K, Glaser B, editors. Biochar in European Soils and Agriculture: Science and Practice. New York: Routledge; 2016. pp. 136-164

[98] Liu J, Schulz H, Brandl S, Miehtke H, Huwe B, Glaser B. Short-term effect of biochar and compost on soil fertility and water status of a Dystric Cambisol in NE Germany under field conditions. Journal of Plant Nutrition and Soil Science. 2012;**175**(5):1-10

[99] Yanai Y, Toyota K, Okazaki M. Effects of charcoal addition on N_2O emissions from soil resulting from rewetting air-dried soil in short-term laboratory experiments. Soil Science and Plant Nutrition. 2007;**53**:181-188

[100] Spokas KA, Reikosky DC. Impacts of sixteen different biochars on soil greenhouse gas production. Annals of Environmental Science. 2009;**3**:179-193