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Biochar: A soil conditioner and Disease Suppressor

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Abstract

Biochar, a solid by product of thermal decomposition of organic matter in oxygen deficient environment has gained international attention and interest among the growers as soil amendment in agriculture for the sustainable management of nematode disease. This review mainly focuses on the potential role of biochar as soil conditioner and nematode disease management. However, currently due to the very limited known information regarding the mechanism involved against the nematode disease, agronomic characters and soil health benefits is not properly understood. Biochar act as a positive effectors and promoter of growth productivity and reduction in the suppression of nematode disease. Soil organic amendment on decomposition release different organic acids and toxic chemic compounds having biocidal activity which might results in the suppression of nematode reproduction and thereby lowered in the reduction in the nematode infestation. Beside this biochar shows various positive effect in terms of including improvements in soil pH, neutralization of phytotoxic compounds in the soil, increased water and nutrient retention, improved soil physical properties, increased soil cation exchange capacity, promotion of mycorrhizal fungi, and turnover in the frequency of soil microbial populations. Incorporation of biochar caused the revamp in the soil rhizospheric microbial populations but the mechanism behinds this is not understood, and may triggers in engendering the positive shift in the favour of beneficial populations of soil microorganism that cause the enhancement in plant growth and resistance to various biotic stresses. Meager evidence of biochar are there for the induction of plant protection against soilborne nematode diseases. Corroborations are there regarding the involvement of systemic acquired resistance (SAR) and induced systemic resistance (ISR) pathways through the biochar triggeration.

Introduction

Biochar is the pyrolyzed carbon rich charred biomass produced through the crop residue, wood, manures and waste of natural origin. It has gain immense attenation and interest as soil amendment due to their carbon(C) sequestering while concurrently improving soil health and important agents for the nematode disease management. The principal centre of focal point of this report is to furnish a critical scientific review of the present scenario in respect to the effects of exploration of biochar on soil properties and nematode management programme. Till date, most studies have focused on the effect of biochar on soil amendment [1,2], with little emphasis on its biological effect. Although few studies [3,4] have indicated that biochar can promote the activity of micro-organisms, there is little evidence of its effect on soil fauna. Soil nematodes are the most numerous mesofauna and occupy all consumer trophic levels within the soil food web [5,6]. Other commonly reported effects of biochar addition to soil are retention of nutrients and an increase of the organic carbon content [7,8]. Biochar soil amendment has been considered to mitigate global warming, restore degraded lands, and offset water pollution by removing organic contaminants such as pesticides, dyes, pharmaceutical and personal care products, perfluorooctane sulfonate, humic acid, and N-nitrosomodimethylamine [9,10]. Biochar addition to cultivated land may be a potential tool for C sequestration by adding the bulk of recalcitrant C resistant to decomposition thus lessening GHG emissions [11,12]. Once added to soils, biochar is stable with the potential to store soil C for several hundred years and may provide other benefits such as improved water holding capacity (WHC) and nutrient supply [13,14].

Impact on soil quality

Biochar is known to improve physico- chemical and biological properties of the soil with the enhancement of soil fertility and nutrient availability. Biochar helps to improve the supply of essential macro- and micronutrients for plant growth mainly in acidic soils [15,16]. Biochar soil amendment also improves soil structure by significantly increasing soil porosity and aeration [17], and microbial activity of beneficial organisms. Biochar strongly influences the composition and abundance of

the soil microbial community, depending on its taxa, and the source and production technology of specific biochar, and thus plays a critical role in nutrient cycling [18,19]. In addition to this utilization of biochar promote Sorption of toxic agrochemicals thus thereby leads to the reduction in leaching and uptake by crop plants. Biochar application also helps to improve ion exchange capacity [20-22]. Biochar application increases soil pH, porosity, and WHC and stabilizes SOM through increased soil aggregation and reduced soil bulk density (SBD) and tensile strength [23-25] Commonly biochar particles have low density with high porosity compared to that of soils which aids soil to hold more air and water, thus decreasing the SBD [26].

Biochar addition to the soil causes alterations in soil health [27,28]. Biochar is suggested to have several potential benefits, including C sequestration [29], reduction of nitrous oxide (N2O) emissions from agricultural soil, stimulation of soil microbial activity [30], sorption of pesticides Kasozi et al. [31] and nutrient ions [32], improvement in soil structure and retention of soil moisture Jones et al. [33] and control of soilborne diseases [34]. Thanks to biochar to have so much properties, which ultimately results in the improvement of soil health and exaggeration conditioning beahviour for the enhancement of soil rhizospheric activity and crop yield.

Impact on soil biota

Soils form the most complicated biological system on the surface of earth containing as many as a million taxa in a 10g sample [35]. Biological communities inhibited in the soil represent complexity and variness in their structure and functions. It is known that the microbial biomass to increase as a result of biochar additions, with significant changes in microbial community structure and enzyme activities [28,36].

Biochar exhibits a positive impact on mycorrhizal fungi [37,38]. Some arbuscular mycorrhizae (AM) increase root colonization sites in the presence of biochar [39]. Biochar can also increase mycorrhizal plant associations, enhancing P availability. Pietik¨ainen et al. [40] argue that microbial abundance may increase due to sorption of bacteria to biochar surfaces, rendering them less susceptible to leaching loss. The phenomenon will be more effective on bacterial community than fungi owing to their small size. Warnock et al. [39], biochar influences soil AM fungi and ectomycorrhizal (EM) by altering nutrient availability, other soil microbial communities like phosphate-solubilizing bacteria, plant-fungi signaling, and habitat creation and shelter from hyphal grazers; however, all these mechanisms are innately interconnected. The short-term increment in microbial activity and population immediately after biochar application is attributed to the labile components associated with the freshly added biochar [41,42]. Jones et al. [33] reported that biochar application appeared to shift the microbial decomposer community toward a bacterial-dominated one. Besides, microorganisms, such as rhizosphere bacteria and fungi, may facilitate plant growth directly [43,44]. In summary, changes in microbial community composition or activity induced by biochar may affect nutrient cycles and plant growth, as well as the cycling of soil organic matter [45]. biochar modifies the community of soil microorganisms as well as their activity, probably because it provides a suitable habitat for them [40]. This is likely to improve directly and indirectly plant growth [46].

Impact on nematode management

Few studies, however, investigated the effects of biochar on plant parasitic nematodes. Zhang et al. [47] reported a decrease in the population of several nematodes, e.g., Hirschmanniella and Pratylenchus in wheat fields amended with biochar. Perry & Beane [48] who reported no suppressive effect of activated charcoal on the final population density of G. rostochiensis in soil. Most importantly, Viger et al. [49] used higher concentrations (5%), and it is known that an excessive activation of plant growth causes a negative effect on plant defense because of resource-limited trade-off effects. Perry & Beane [48] who demonstrated a delay in hatching of J2 of G. rostochiensis when potatoes were planted in soil amended with activated charcoal. Nematode genera belonging to fungivores preferred biochar-enriched environment to get more microbial resource as food [4], while those belonging to plant parasitic group favoured environment with no or low biochar to avoid the competition of microbes [50]. Biochar produced from citrus wood using traditional charcoal-making techniques was found to induce systemic resistance on foliar fungal pathogen, Botrytis cinerea (gray mold) on pepper and tomato and to the broad mite pest (Polyphagotarsonemus latus) on pepper [34]. Fusarium infection of Asparagus was found to decrease after addition of coconut biochar and was similar to the benefits derived from manure made from coffee residue [51]. A decrease in Fusarium infection of Asparagus was also reported after addition of biochar made by fast pyrolysis of wood powder [52]. Infection of tomato with another soil borne disease, bacterial wilt (Ralstonia solanacearum), was significantly reduced by adding wood biochar in some experiments and consistently by adding biochar made from municipal biowaste [53].

A 1.2% concentration of biochar added to the potting medium of rice was found to be the most effective at reducing nematode development in rice roots, whereas direct toxic effects of biochar exudates on nematode viability, infectivity or development. The increased plant resistance was associated with biochar-primed H_2O_2 accumulation as well as with the transcriptional enhancement of genes involved in the ethylene (ET) signaling pathway. Significant differences in nematode mortality were not observed between biochar exudates (6.6±0.7 %) and water (7.2±0.6 %) 24h after initiation of the bioassay at doses ranging from 0.3 to 5% biochar. Similar results were also observed when the nematodes were incubated in biochar exudates for 72 h. These data suggest that biochar exudates do not have a direct nematicidal effect on M. graminicola at the doses tested [54]. Root length of rice was shown to increase with biochar additions. Germination and rooting of fir embryos (Abies numidica) significantly increased from 10 to 20% without additions to 32-

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80% of embryos when activated carbon was added to various growth media [55]. Soil biochar incorporation has a positive impact on beneficial fungi Atkinson et al. [4] which would support more fungivorous nematodes. When comparing the root knot nematode infected plants with no infected plants, slight but significant reductions in the root length and total plant height were observed in the root knot nematode infected plants. The number of adult females in biochar-amended roots was slightly lower than that of non-amended plants [54]. The amendment of poultry-litter biochar to the soil generally decreased the number of plant-parasitic nematodes while increasing the amount of free-living nematodes in the soil (Rahman et al. 2014). Certain biochar additions to soil have been shown to significantly improve the soil tilth, nutrient retention and availability to plants, and crop productivity.

Ebrahimi et al. [56] demonstrated that although biochar significantly delayed hatching of both potato cyst nematode species but it did not reduce the final number of juveniles that hatched and penetrated the roots during the growing period. On the contrary, when plants were inoculated with hatched J2, fewer juveniles were detected in the potato roots in soil amended with pig slurry, cattle slurry, mineral nitrogen, wood chip compost and crab shell compost, but not with biochar. Adding biochar at 0.3 and 1% did not reduce the survival or the reproduction of any of potato cyst nematode species; moreover, it inhibited the suppressing effect of wood chip compost and pig slurry on potato cyst nematode reproduction when added together with these amendments. Bio-assays were developed to assess the effect of biochar soil amendments on the soil-borne plant-parasitic nematodes Meloidogyne chitwoodi on bean and carrot, Globodera sp. on potato. Incorporation of 3% (DW) biochar produced from holm oak at 650 °C in peat significantly reduced the incidence of Botrytis cinerea on strawberry leaves; whereas 1% (DW) amendment had no effect. Compost amendment reduced the plant-parasitic nematode population on carrot and potato, but this effect was absent in case of additional biochar application [57]. The experiments have shown that the addition of biochar to a grape vineyard reduced the incidence of plant parasitic nematodes by a factor of eight compared to the control (Rahman, 2014). The biochar treatment had 82.5% less nematodes compared to the highest population achieved and it may contain bio-toxic compounds. There was a sharp drop in total nematode population compared to the control on tomato [58]. Vaccari et al. [59] found that the use of biochar on tomatoes increased plant growth compared to non-amended control for processing tomatoes. An increase in cherry tomatoes was also seen with the addition of biochar, which increased production by 64% compared to control [60]. Biochar soil application resulted in higher upland rice (Oryza sativa) grain yields at sites in northern Laos with low P availability, and improved the response to N and NP chemical fertilizer treatments [61]. Five different soil amendments (Nostoc calicola amended compost, bokashi, biochar, garlic straw, and compost) were applied at 500g /pot. Plant performance, and nematode incidence and diversity were analyzed in Lycopersicon esculentum cv. Capppricia. The results indicated that there were no significant differences ($p>0.05$) in plant height, stem diameter, leaf sap analysis (N, K, P, Ca, NO3, NH4, Mg, Zn, Mo, Cu, Fe, Mo, Se, Cl, Al, and Mo), tomato fruit production, and root knot index among treatments. Root knot index (RKI) values were unexpectedly low which seems to be indicative of relatively low nematode pressure. Significant differences were observed in leaf count; stem final fresh weight, leaf final fresh weight, with the garlic straw treatment having the highest average means. In terms of total nematode populations, bokashi+garlic straw showed the highest values compared to the other treatments (Abdurrahman MEA Al-Fraih, 2015). Breazeale [62] have explained the pronounced increase in root growth after additions of carbon black (soot) to soil with sorption of allelopathic compounds that were phytotoxic. In several cases, not only root and shoot biomass increased after biochar additions, but the shoot-to-root ratio increased, as well Lehman et al. [63] Such an increase in the shoot-to-root ratio may indicate improved resource supply that requires fewer roots to sustain the same above-ground biomass production [64-66].

Conclusion

From this study we can conclude that the impact of biochar on the plant-soil system is not governed by the singular factor but it is the outcome of multiple factors. From the literature it was claimed that the biochar can alter physicochemical and biological properties of the soil, plant growth, disease resistance and microbial communities in the plant-soil system. Therefore further in future studies we should pay attention on the effect of altogether component such as biochar on the plant, the soil and the microbial system. In addition to this one of the most amazing and environmentally protective property of biochar in soil-can augmenting sequestration of SOC, soil conditioning, boosting the productivity and plant health as well as enhancement in fertilizer efficiency, global food security and climate change. In the same manner, these process favours various ecosystem services in the form of suppression soil erosion and disinfection of water sources and ecosystem health. Beside this biochar release certain toxic chemicals that inhibited the nematode reproduction and triggers plant defense. Further characterization is needed to identify these chemicals present in the biochar exudates released after the decomposition. These multiple advantage of biochar makes it potentially a very attractive and necessary tool of the hour for sustainable soil health and management of nematode disease. An explained and well developed mechanism is required to reveal the mechanisms undergoes in various biochar effects on soil health, find out and characterize the optimal application rates of biochar and its relation and matching to various soil and climatic conditions and further examined the biochar quality parameters.

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