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Review Paper

Biochar Soil Amendment: Effect on Soil, Crop Performance, and Diseases Resistance

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***Abstract*— One of the main challenges facing developing countries is an ever-increasing gap between population growth and food supply. Diseases, insects, and weeds decrease the production of crops worldwide by 36%. Hence, control of crop pests contributes to increased crop production. Organic amendments to the soil have direct impacts on crop productivity and plant health as it enhances soil fertility, water, and nutrient retention and plant disease defense mechanisms. Biochar is an important organic amendment. It is produced by the pyrolysis process, whereby organic substances are broken down at higher temperatures in low oxygen conditions. Biohar improved soil nutrient availability and water retention capacity, and induced plant resistance against broad ranges of plant pathogenic organisms including fungi, nematodes, and bacteria. Biochar soil amendment also enhances root-associated microbes such as flavobacterium and arbuscular mycorrhizae. Biochar amendments can increase soil essential nutrients for crop productivity and suppress plant pathogens. Suppression of plant pathogens is attributed to the stimulation of beneficial soil microbes, providing nutrients, and inducing plant defense. The objectives of the review are to depict the importance of biochar soil amendment on crop performance, disease resistance, and soil properties.**

Keywords*— Biochar, induced resistance, Soil microbes, Pathogens

I. Introduction

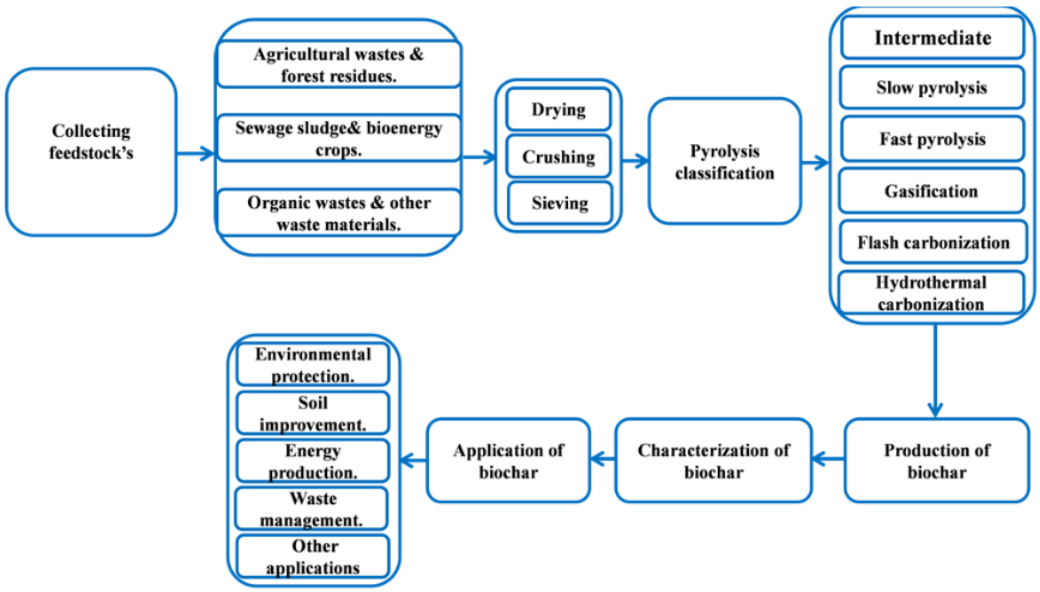
Soil fertility status influences not only crop performance but also compromises plant disease resistance potential. Long-term soil amendment and soil fertility have significant effects on soil disease suppression. Such soil types can not only affect the development of soil-borne pathogens (*Rhizoctonia solani, Pythium ultimum*) but also the resistance of plants to airborne diseases (*P. infestans, Hyaloperonospora parasitica*) [1]. In addition to this soil organic matter amendment, it enhanced soil microbial populations and soil disease suppressiveness via the promotion of native beneficial microbes and/or the introduction of new beneficial microbes [2, 3]. Biochar has become an essential organic soil amendment. Biochar is a charcoal-like material produced by the thermochemical pyrolysis of biomass [4,5]. According to the European Biochar Certificate [6], biochar is produced by biomass pyrolysis, a process whereby organic substances are broken down at temperatures ranging from 350 to 1000°C in low-oxygen thermal processes. It produces solid, liquid, and gas products [7]. The solid (biochar) will be used for soil amendment. Interestingly, biochar soil amendment is a carbon-negative process that persists in soil for hundreds of years and serves as a tool for carbon sequestration [8]. Biochar is found in soils around the world as a result of intentional or unintentional soil management and vegetation fires [9].

II. SOURCES OF BIOCHAR FEEDSTOCK

Biochar materials (feedstocks) can be a wide range of plant materials and their by-products. Feedstocks must be free of non-organic wastes such as plastic, rubber, electronic scrap, and paint [6]. Several researchers across the globe utilized a variety of organic materials as biochar feedstocks, including forestry wastes, poultry litter, municipal solid wastes, crop residues, cattle manure, and food industry waste. In Canada, biochar is produced from maple bark, cherry, eucalyptus bark, spruce branches, coconut shell, willow, cabbage residues, non-marketable potatoes, leek residues, corn cobs, pigs, and poultry manure [10]. Other biochar feedstocks include citrus wood [4, 11], rice hull [5], wood chips [10], greenhouse wastes [12], and pine wood, bark, and spelled husks (13). Biochar's chemical and physical properties depend on production temperatures and organic material types [14, 58].

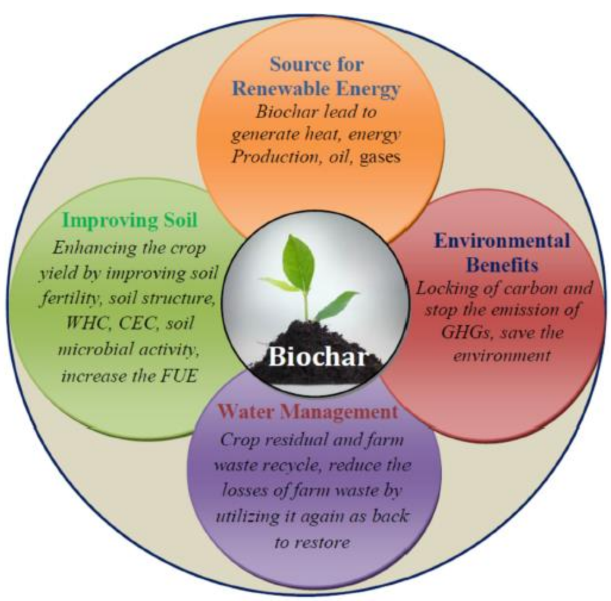
III. EFFECTS OF BIOCHAR APPLICATION ON SOIL PROPERTIES

Biochar soil amendments play a vital role in carbon sequestration and climate mitigation. Biochar stores carbon for long periods [7]. It also increases methane uptake by 96% [16]. The benefits of biochar are becoming more widely known as research has revealed its biological and physiochemical properties [6]. Some of the benefits of biochar include soil conditioning, compost additives, carriers for fertilizers, manure treatment, feed additives, etc. [6]. Multiple research results found that biochar application to soil improved soil nutrients and water retention capacity [15, 16]. Biochar amendments can increase total soil N, K, and P, all essential nutrients for plant growth [16, 48]. It also increases soil organic C and cation exchange capacity and decreases soil bulk density [16]. Furthermore, it neutralizes phytotoxic compounds in the soil, improves soil physical properties, and reduces soil strength [17]. Biochar soil treatment benefits go beyond improving soil water and nutrient retention. It improved soil chemical properties such as pH, total C, and N, C: N ratio, CEC, Mg, and Ca, and also significantly reduced ammonium leaching by up to 46% [18]. Biochar has an excellent adsorption capacity and reduces nutrient leaching by retaining nutrients from the soil, both native and added as fertilizers [49]. Moreover, biochar-treated soil enhanced beneficial microbe diversity and population. Research results indicated that biochar-amended soil enhances mycorrhizal fungi [19, 20], improves root-associated bacterial communities [4, 11], and alters soil microbial populations and functions [21, 22, 23]. In the near future, biochar use will increase rapidly in agriculture sectors as its benefits are multiple and ecologically compatible.



Source; Mohammed (2017)

Fig.1. flowcharts of biochar production



Source; Jatav etal., (2021)

Fig.2. potential effects biochar for sustainable managements in agriculture

IV. EFFECTS OF BIOCHAR APPLICATION ON CROP PERFORMANCE

Long-term intensive agriculture has resulted in soil nutrient depletion and salt accumulation, thus significantly reducing the ability of soil to support a growing world population [24]. Biochar soil amendment is essential as it significantly improves soil tilth, nutrient retention, and availability to plants, and more importantly, enhances crop productivity [25, 3]. Biochar soil application improved crop performance in areas with severely depleted soil organic resources, inadequate water, and chemical fertilizer supplies [9], as it improved soil nutrients and water retention capacity [17]. According to [13], carrots grown on biochar-treated soil produce two to four times more biomass than untreated soil. Similarly, biochar-amended soil increases the final biomass of lettuce and cabbage compared to untreated soil [26]. Biochar soil amendment research resulted in a significant increase in the number and weight of pepper fruits, and the total cumulative yield in the control was 8.1 kg/m2, while in the treatments it reached 11.8 km−2 [27]. In similar research, biochar-amended soil increased the yield of rice and wheat (23). According to [19], biochar-amended soil significantly improved root growth and the shoot-to-root ratio of oil palm seedlings. Enhanced crop performance as a result of biochar soil amendment is attributed to its myriad effects, including, increased nutrient retention [3, 17, 2], improved soil pH, increased soil cation exchange capacity [29], effects on P and S transformations, and turnover [30], and neutralizing phytotoxic compounds in the soil [17].

Interestingly, biochar soil amendment promotes mycorrhizal fungi [31] and alters soil microbial populations and functions [4, 24]. According to [11], biochar soil application improved the root-associated bacterial community (Flavobacterium) on pepper. Members of the Flavobacterium genus are widely distributed and play a role in mineralizing various types of organic matter, such as carbohydrates, amino acids, proteins, and polysaccharides [32].

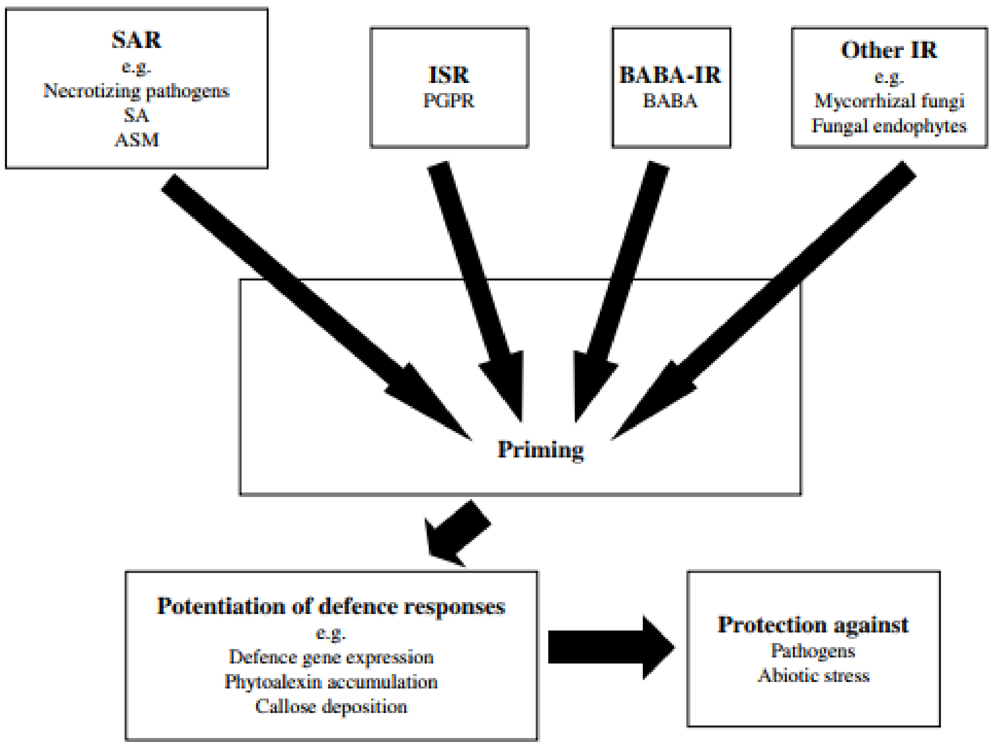
V. EFFECTS OF BIOCHAR SOIL APPLICATION ON PLANT DISEASES RESISTANCE

Long-term soil amendment and soil fertility have significant effects on soil disease suppression. Such soil types can not only affect the development of soil-borne pathogens (R. solani, P. ultimum) but also the resistance of plants to airborne diseases (P. infestans, H. parasitic) [1, 63]. In addition to this, soil organic matter amendment has shown improved soil microbial populations and soil disease suppressiveness via the promotion of native beneficial microbes and/or the introduction of new beneficial microbes [2, 3, 33, 50, 51]. According to [34], organically amended soil induces plant defense mechanisms against multiple plant pathogens. Biochar-amended soil induced systemic plant resistance against foliar pathogens such as gray mold (Botrytis cinerea) on tomatoes and powdery mildew (Leveillula taurica) on peppers and also stimulated beneficial soil microbial consortiums [4]. Similarly, biochar-amended soil significantly reduced tomato bacterial wilt disease [23, 52] and increased soil microbial density as well as activity [23]. Likewise, biochar and compost application to the soil exhibit great potential for suppressing Fusarium chlamydospore infectivity and alleviating pathogen-induced stress on tomatoes[39]. Application of black carbon to soil enhanced plant pathogen resistance due to 69% increased colonization by Arbuscular mycorrhizal fungi (AMF) on Asparagus officinalis [35]. Similarly, a 42% increase in root colonization by AMF was found following charcoal soil treatment [36, 52]. Biochar soil application improved root-associated bacterial communities Flavobacterium genus on pepper [11]. The Flavobacterium genus often possesses an arsenal of extracellular enzymes, such as proteinases and chitinases, which enable them to degrade bacteria, fungi, insects, and nematode constituents [33]. Flavobacterium isolates isolated from crops such as sunflowers, apples, and bananas were highly antagonistic to soil-borne fungal pathogens such as Lasiodiplodia theobromae, Colletotrichum musae, and Phytophthora cactorum [37, 38]. In addition, this biochar-amended soil significantly decreased the severity of pepper powdery mildew disease and broad mite pest infestations. Powdery mildew severity after 160 days of planting was 75.2% in the control and significantly reduced to 46.4% in the biochar treatments [27]. Furthermore, disease incidence on the newly formed pepper canopy was significantly reduced to 36.0% in biochar treatments as compared with 60.6% in the control [27]. Similarly, adding biochar to strawberry potting medium significantly suppressed anthracnose, gray mold, and powdery mildew diseases [12]. Interesting strawberries grown on biochar-added pots expressed defense-related genes against gray mold and powdery mildew pathogens [12]. Use of biochar from greenhouse waste in tomato against B. cinerea induced priming of early- and late-acting defense responses including an expression of genes related to jasmonic acid and ethylene responses, and a high accumulation of active oxygen species such as H2O2 crucial in the resistance against B. cinerea [54]. Biochar addition to soil enhanced cucumber growth and suppressed Rhizoctonia solani [14]. Biochar treated soil reduced the severity of soybean root rot (Fusarium virguliforme) [40]. Carrots planted on biochar-amended soil significantly reduced tap root infection rates of the root lesion nematode (Pratylenchu penetrans) by 80% [13]. Similarly, biochar from log wood was effective in reducing the populations of P. coffeae, root lesion nematode of banana [55]. In grapevine, biochar from poultry litters significantly reduced nematodes populations present in soils, including Meloidogyne javanica, Tylenchulus semipenetrans, Pratylenchus spp., Helicotylenchus spp., and Criconemoid spp., due to an increase in the diversity of plant-beneficial organisms [56]

To date, biochar-mediated influences have been shown for 15 different pathogens (fungi, oomycetes, and nematodes) in 30 different host-pathogen systems [41]. Biochar suppression of plant pathogens is attributed to the stimulation of microbes that provide direct protection against pathogens via antibiosis/ fungitoxic, competition, or parasitism, adsorbing toxins produced by pathogens (such as extracellular enzymes and organic, promotion of plant growth by providing nutrients, increasing soil-microbial diversity, and induction of plant defense mechanisms against the pathogens [47, 50, 51].

VI. INDUCED PLANT DISEASE RESISTANCE

Biochar suppression mechanisms of plant pathogens are similar to compost suppression mechanisms of soil pathogens: stimulation of microbes that provide direct protection against pathogens and induction of plant defense mechanisms [34]. Plant-induced systemic resistance results from the chemical composition of the biochar, as biochar contains phenol, polyphenol, aliphatic hydrocarbons, and other compounds [4]. Induced disease resistance in plants is an enhanced defensive capacity elicited by biotic and abiotic agents [42]. Induction of resistance can lead to the direct activation of defenses and also lead to the priming of cells, resulting in stronger elicitation of acquired and systemic defense following pathogen attack [43]. Induced resistance is effective against fungi, bacteria, viruses, and nematodes [44] and abiotic stress [42]. The most defined forms of induced resistance are systemic acquired resistance (SAR) and local acquired resistance (LAR) [45]. SAR occurs when plants develop broad-spectrum systemic resistance to pathogen infection [45] and associated with the production of pathogenesis-related proteins and salicylic acid-dependent processes. LAR develops in response to root colonization by plant growth-promoting rhizobacteria and fungi and mediated by jasmonic acid and ethylene signal pathways. LAR acts against a wider range of pathogens [46].



Sources: Walters and Fountaine (2009)
Fig3. SAR and ISR events in plant

VII. CONCLUSIONS

Research results have shown the benefits of biochar-treated soil, including improved physical, chemical, and biological properties, increased crop productivity, and enhanced plant defense mechanisms. Biochar suppression of plant pathogens is attributed to a myriad of mechanisms similar to compost suppression of soil pathogens: Hence, it is imperative to scale up biochar application to the soil to minimize pesticide application, reduce mineral fertilizer dependency and cost of crop production, and, more importantly, to encourage ecol-friendly plant disease management methods. This is particularly important for organic farming as well as farmers in developing countries where fertilizer and pesticides are expensive. Biochar soil application could be very vital to greenhouse producers as it generates a bulk of plant waste that could be used as biochar feedstock material. Despite the multiple benefits of biochar application to the soil, cost-benefits of biochar soil application and crop, and the amount of biochar per hectare should be determined for optimal biochar utilization.

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