International Journal of Theoretical & Applied Sciences, 11(2): 29-40(2019)

ISSN No. (Print): 0975-1718
ISSN No. (Online): 2249-3247

Biochar: Preparation, Properties and Applications in Sustainable Agriculture

Ashaq Ahmad Dar[1], Mohd. Yousuf Rather[1], Javid Manzoor[2] Waseem Yaseen[3] and Khursheed Ahmad Wani[3] and Dheeraj Vasu[4]
[1]Department of Ecology and Environmental Sciences, Pondicherry University, Puducherry India.
[2]Department of Environmental Sciences, Shri JJT University, Rajasthan, India.
[3]Department of Environmental Sciences, Govt. Degree College, Bijbehara, India.
[4]Department of Botany, Safia Science College Bhopal, (M.P.), India.

(Corresponding author: Khursheed Ahmad Wani)
(Received 30 September, 2019, accepted 19 November, 2019)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: A large number of population in the world is dependent on agriculture and its products. However, with the growing population the need for different agricultural products has increased over a period of time. The agricultural soil has been degraded by the use of synthetic fertilizers. Different methods are developed by the researchers to restore the degraded soil ecosystems. Among the different options available, use of biochar is a viable option. The biochar is carbon rich has emerged as a possible option for restoration of degraded land and to increase agriculture efficiency in numerous frameworks and carbon fixation. This paper is an attempt to study the applications of biochar for the sustainability of agricultural ecosystems.

Keywords: Biochar, Soil, Degradation, Sustainable agriculture.

I. INTRODUCTION

Sustainable agriculture is highly promoted as it is considered to be a safe practice as compared to conventional method. With the ever-changing global population's growing demands, a realistic solution to sustainable agricultural activities has become indispensable for nourishing. Soil degradation processes *viz.,* soil erosion, compaction, lack of water holding capacity (WHC), reduced cation exchange capacity (CEC), acidification, poor fertility, organic and inorganic contamination, salinization, urbanization and changing climatic conditions jeopardizes global food stability contributing to extreme economic restrictions that entail the creation of innovative and environmentally sustainable innovations that boost soil quality and resilience [43]. Moreover, decreasing arable land area as well as agriculture yield due to global warming endanger people round the world through poverty and malnutrition. Sustainable agriculture is a field of increasing contemplation as it focuses on viable ways of processing crops in an environmentally sustainable, socially equitable and economically advantageous manner that can be maintained over the long term [53].

Sustainable agriculture is the integration of the biological, natural, technical, cultural, economic and social sciences in a holistic way to establish modern, healthy and environmentally sustainable farming practices [84].

The green revolution has fed the inevitably growing population over the last 40 years, but is generally considered to be incompetent, environmentally cataclysmic and unlikely to fulfil requisition (Barrow, 2012). Furthermore, the global population which is projected to rise to 9.6 billion by the mid of 21st century, would eventually result in rising demand for food that too from shrinking arable land availability [134].

Agriculture is one of the predominant producer of greenhouse gas emission (GHG), particularly methane (52 %) and nitrous oxide (84 %), with just under 25% of total human induced GHGs in the year 2014, mostly attributable through land use shift and forestry [119]. Hence, developing successful sustainable agriculture practices that can reduce agricultural GHG emission share with enhanced yield has become more urgent than ever. These shortcomings of green revolution set up the scene for a revolutionary paradigm (Sustainable agriculture) establishing a collaboration of conventional farming structures with advanced technology schemes. The campaign for sustainable agriculture started in 1980s and is an economically feasible, environmentally responsible and socially equitable method of agricultural development [84].

There is a notable rise in research work on the usage of naturally produced products to be incorporated in the sustainable agriculture. Many of these bio-stimulants such as humic and fulvic acids, organo-mineral fertilizers and biochar which are environmentally benign are believed to enhance soil fertility, plant growth thus, agronomic productivity apart from abiotic and biotic stress tolerance [1, 14, 94, 125]. As a soil additive generated from waste biomass through pyrolysis, biochar has earned noteworthy consideration as a possible strategy to enhance the management of agriculture soils [99]. It is noteworthy that biochar is effective in all forms of farming systems unlike other organic materials [21, 137].

Biochar, a pyrolytic organic material generated under oxygen-deficient conditions within a temperature range of 300°C – 1000°C. The biochar being carbon rich has emerged as a possible option for restoration of degraded land and to increase agriculture efficiency in numerous frameworks and carbon fixation [74, 87]. The practice of using biochar in agronomy is not new and dates back to hundreds to thousands of years ago when Amazon inhabitants generated it by heating to develop rich, prolific soils called *terra preta*. Without extra fertilization, *terra preta* soils are reported to grow more than one harvest a year, in addition to exhibiting slightly greater potential for cation exchange [46] Steiner et al., 2008) and larger soil carbon stocks [46]. The potential of biochar to function as efficient soil alteration is somewhat similar to conventional slash and burn agriculture practice. However, the custom of slash and burn has an adverse environmental legacy as it is directly related to erosion and also retards the ambient air quality. The processing of biochar in contrast, a regulated method will produce higher yield and have less adverse environmental consequences. Biochar being impervious to microbial deterioration due to its obstinate aromatic carbon structure can retain in the soil as long as 100 – 1000 years thereby increasing and releasing soil organic carbon slowly. Nevertheless, such attributes make biochar an excellent soil additive to be used in sustainable agriculture [74].

Despite the fact that biochar application has produced some variable results contingent upon soil quality, feedstock for biochar preparation, pyrolysis temperature, and other natural elements. There are various potential implications related with the utilization of biochar added either alone or in conjunction with calcareous material or inoculant [25, 102] *viz.,* enhanced soil nutrient accessibility and their absorption [113, 156] upgraded fertilizer (both organic and inorganic) use proficiency [125], ameliorate soil pH [75], improved mineral nitrogen retention [30], reduced nitrogen loses and demand for fertilizers (Ding et al., 2016) [33], increased seed germination success rate, strengthening soil properties [10], improved base saturation and liming impact on acidic soils [141], heavy metal fixation colonies [3, 100] incitement of microbial [154], improved crop productivity, efficiency and enzyme production [58], improved leguminous symbiotic N fixation (Mia et al., 2014), safeguards plants and soil from detrimental impacts of salinity, drought and heat stress [4, 36, 39]. Biochar additionally provides a worldwide negative emanation capability of 0.7 Pg C yr^{-1}, and has been demonstrated to be successful for decreasing soil greenhouse gas fluxes in certain contexts thereby, besides curtailing methane fluxes from paddy cultivation thereby increasing microbial activity and minimizing shifts in the global climate while managing biowaste [8, 51, 116]. Its surface area and complex pore structure are cordial to microorganisms that plants need to assimilate supplements from the ambient soil environment.

Therefore, the chapter examines the phytoremediation process, its context, and also discusses various methods, factors affecting the process, its advantages, and disadvantages in view of the need to acquire information about biochar and its application in sustainable agriculture. By addressing the remediation of mercury, cadmium, and lead-contaminated soils, the chapter also assesses the value of phytoremediation technology.

Biochar: production and characteristics

Biochar, a pyrolytic product, produced from all organic materials such as forestry wastes, animal manures and crop residues via thermal decomposition under oxygen deficient conditions [5]. Age-old traditional pyrolysis systems exhibit slower heating rates, thus holding the material for a prolonged time period besides high production yield (94% at 300°C and 23% at 750°C for hardwood) [63]. In contrast, fast-pyrolysis systems drastically reduce the residency time besides providing a range of products such as bio-liquid apart from biochar and syngas [48] depending upon the temperature, heating rate, vapor residency time and reaction time during pyrolysis [123]. Biochar produced with the latter process includes a fraction of labile unpyrolysed biomass supporting a carbon loss in addition to greater microbial content. Moreover, quickly pyrolysed material can possibly sequester carbon supplying a base for N retention at the same time. It was demonstrated that production curtailment appeared with scaling-up processing temperature, despite stimulating conclusive alterations to biochar structure [7]. Moreover, feedstock moisture content firmly impacts the effectiveness of pyrolysis. Feedstock with a moisture content of <10% is preferred [105]. Biochar properties fluctuating with processing temperature include pH, volatile matter, while the feed-dependent properties are absolute carbon content, ash content, cation exchange capacity, thermal stability, production rate and mineral composition [5, 151]. As the biochar production varies with the processing temperature despite from the same feed material, a blend of optimal pyrolysis parameters, in particularly the temperature and kind of feedstock, ought to be chosen for the nature of biochar required for farming and ecological purposes.

Biochar usually display alkaline pH, with the exception of certain softwood (e.g. pinewood) and hardwood (e.g. black locust wood) tree biomass as they exhibited a neutral or just under neutral pH and thus, can find applications to treat alkaline soils. In contrast to pH, CEC of biochar is more reliant on feeding material (higher in crop straw derived biochar), which could be linked with degradation of certain functional groups of acidic nature, as opposed to pyrolysis temperature [71, 151]. However, ash content fluctuates with both feedstock incorporated and processing temperature [37, 71]. It was also reported that ash content showed a correlation with electric conductivity, CEC, pH, and mineral composition [8, 151]. Similarly, electric conductivity also varies significantly with material used and also with operating temperature [7, 115]. From agriculture perspective, salt concentration is crucial as many crops are prone to high salinity in soil or water system. Nonetheless, for structuring biochar, the salt concentration of the biochar ought to be thought of (Laghari *et al.,* 2016) [71]. Although the elemental composition of the biochar mainly depends upon the biomass used, the role of the processing temperature cannot be underestimated. For example, nutrient content of the biochar increases with the temperature elevation (C and N), mainly ascribed to thermochemical transformation under oxygen-deficient conditions, up to certain extent (< 700°C), nevertheless P and K loss was reported thereafter [69, 148]. It is generally believed that low-pyrolysis temperature biochar (300–500ºC) can have a stronger effect on agrarian framework that could be due to increased surface area, aliphatic compounds, CEC, labile carbon, hydrophobicity, nutrients, and lower alkalinity and salinity, whereas, fast pyrolyzed biochar contains more aromatic compounds and fixed carbon, and is ideal for soil carbon sequestration [7]. Following the recommendations of the International Biochar Initiative (IBI) biochar is portrayed by proximate investigation *i.e.,* fixed, carbon, ash and moisture contents, and volatile matter, essential examination i.e., C, H, O and N, and chemical and structural investigation i.e., pore size, functional groups, pH, EC etc.

Biochar as soil physico-chemical ameliorator

Biochar induced changes in both physical and chemical properties of the soil can improve the plant growth and hence productivity. The soil pH is considered as an important parameter governing soil fertility. Alterations in the soil pH can improve soil conditions and enhance soil nutrient accessibility to grow plants and biochemical reactivity. The adjustment of the soil condition likewise encourages microbial action and quickens chemical responses in the rhizosphere [54]. Several investigations demonstrate that biochar application can amend pH with application rate. Because of the alkaline aspect of certain biochars the beneficial impact is more prominent for acidic soils [75, 78]. The low soil pH in temperate soils can be increased by treating it with beech wood biochar of alkaline nature thereby improving the alkaline phosphatase activity in the soil matrix [18, 49]. Such findings reflect shifts in microbial behaviour induced by soil pH differences as biochar is added. Moreover, soil pH increment in savannaoxisols upon biochar introduction is ascribed to an expansion of Ca and Mg accessibility thus promoting crop production [90]. Soil acidity leading to aluminium toxicity with calcium, magnesium and phosphorus deficiencies are major threat to crop production as 30% of global arable lands are acidic [38, 153]. Biochar of alkaline nature can be used to treat such soils to overcome the acidity problem besides weathered soils [78]. However, biochar prepared from pine sawdust is predicted to display the contrasting effect i.e., decrease in soil pH, in sandy soils and the effect varies with the application rate [69]. In this manner, care ought to be taken in choosing the suitable acidic or alkaline biochar capable altering the soil as per plant requirements.

Electric conductivity is another essential feature regulating the crop quality as well as productivity. Biochar has been reported to increase electric conductivity ranging from 2 – 85 %. Application of biochar with ash containing soluble salts can lead to improvements in electric conductivity [56]. Cation exchange capacity is an indirect measure of the ability to retain water and other nutrients and contaminants and can reach up to 50 cmol (+) kg^{-1} in biochar [56, 75, 138]. As soon as the biochar is applied to the soil gets exposed to ambient water and oxygen causing unconstrained surface oxidation prompting to elevated anions and hence higher CEC value [2]. The CEC of the transformed soil can be adjusted dramatically depending on the nature of biomass used and processing temperature [108]. Slow pyrolyzedbiochars have moderately high CEC characteristic of its potential for soil improvement [56, 130]. Loss of aromatic carbon through oxidation and formation of carboxylic groups in the biochar may be the reason behind CEC improvement within the soil matrix [45]. Moreover, with time there is an increase in surface area accompanied by negative surface charge and CEC [129]. Therefore, biochar can serve as a sink as well as source for most nutrients that influence plant growth and development and is recommended low fertility weathered soils [129]. As the biochar materials display broader surface area with low bulk density owing to a wide range of pores [35], their application to the soil increases the same thus improving physical properties such as soil aeration, soil structure, density, water retention potential etc [26, 35]. Biochar additionally influences the C/N content of the soil, a key parameter in altering several other soil properties [140].

The availability of water in the soil is fundamental for plant growth. Porosity, soil aggregate stability, and various other hydrological functions are affected with biochar application through several mechanisms [50]. Use of biochar ($\geq$ 15 Mg ha^{-1}) is a competent method for improving soil water retention capability and bio-availability, besides other hydrological properties directly or indirectly via high surface area and increase in organic carbon, respectively [15, 97, 98, 120, 121, 146]. Furthermore, findings propose that the use of low-density biochar amend the overall porosity and aggregation, and hence can diminish the bulk density of the biochar modified soils up to 12% [16, 86]. The decrease can be linearly or quadratically with biochar application and is more prominent in coarse-textured (14.2 %) as compared to fine-textured soils (9.2%) [16, 44, 86, 106]. The large surface area and high porosity governs the alterations in the tensile strength (42 – 242%) of the biochar-soil matrix, that in turn can influence root penetration through soil, seed germination, tillability and other various processes [19]. However, other factors such as bonds among the soil particles, friction, forces, clay and mineral content of the soil, binding mediators, microstructural properties, and organic carbon strongly determines can have a profound impact on soil tensile strength.

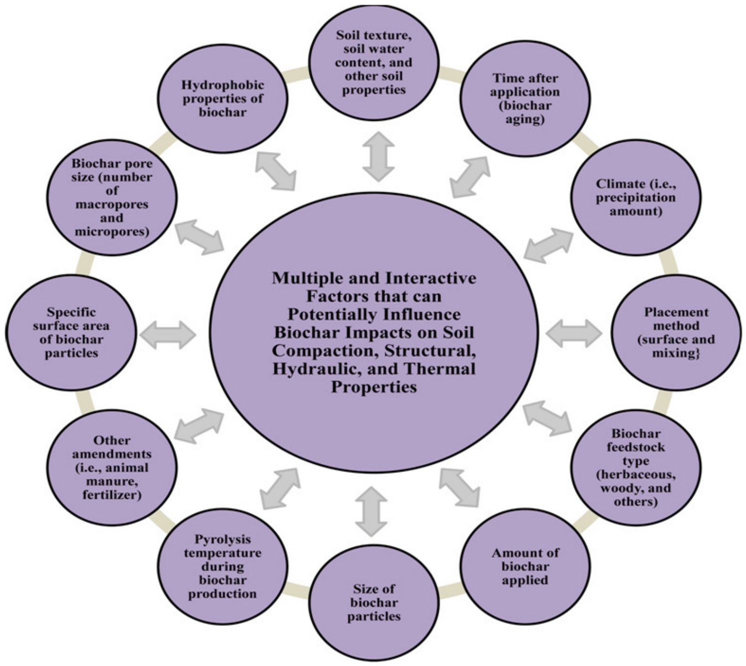

Fig. 1. Factors including soil properties, biochar properties, and management scenarios, and their interactions affect the impact of biochar application on soil physical properties.

Biochar is also known to mitigate soil erosion significantly depending upon the rate of biochar application possibly due to the micro-aggregate formations [59, 110]. Moreover, surface runoff and leaching leading to nutrient loss in farmlands can also be reduced to some extent. These mitigating impacts of biochar on soil overflow and disintegration of soil particles might be credited to the improved water retention capacity in addition to various other physical characteristics. Furthermore, if the climate change prompts much severe dry spells, biochar with significant positive effect on holding soil water can be an option [74]. Taking all these beneficial results into account the use of biochar in sustainable agriculture may be an efficient method to reduce field losses due to soil erosion.

Biochar and greenhouse gas emissions.

Anthropogenic CO_2 effluxes have been rising recklessly pushing Earth's biomes on a trajectory triggering a rapid change in the climate that is dangerous besides irretrievable. Comprehensively, human actions are liable for the allocation of 16 Pg C yr^{-1}, which amounts to 24% of the main net earth production [144]. The food and agriculture organization has reported that agriculture GHG emissions secure the fifth spot contributing approximately 24% of the cumulative anthropogenic greenhouse gas emissions [40, 117]. The CO_2 emitted through soil biota respiration is around multiple times higher contrasted with that delivered from the burning fossil fuel derivatives [96]. To alter this trajectory, a judicious and determined program of mitigating undesirable change is looked-for. To stabilize mean surface temperature, overall human-induced GHG outflows need to be kept under the maximum cut-off limit. Thus, adopting climate-smart activities to cut out surplus CO_2 can enhance farmers' production and economy, thus helping to reduce the negative impacts of climate change. Biochar preparation and its stockpiling in soil has been proposed as one the potential method for diminishing the CO_2 concentration [72, 81]. Techniques of converting plant biomass to biochar can diminish CO_2 outflows by balancing out carbon [73, 90, 127]. Biochar formation significantly lowers CO_2 in the environment, since the mechanism takes a hypothetically carbon-neutral form of biologically rotting material and converts it into carbon-negative. Biochar stagnates the rotting matter and associated CO_2 and places it on the earth to remain for hundreds or perhaps thousands of years. Notwithstanding, the degradable bit of biochar is exceptionally little and decayed rapidly when contrasted with the time it takes to sequester the non-mineralized component [20, 61]. Moreover, biochar disintegration was moderately gradual during the initial three months following its expansion to the soil, and thereafter moderate, halfway decay happened during the accompanying 3.2 years [68]. It has been conjectured that biochar may enhance microbial activity by complex soil organic matter with biochar surface and at the same time trigger the poor priming of natural carbon mineralization within the soil [83, 145]. The conglomeration of SOCs on biochar particles can result in the coordination and integration of substrates, nutrients in addition to microbial biota and thus encourage greater efficiency of C-utilisation by the latter [80]. The activity of glucosidase and cellobiosidase, the carbohydrate mineralising enzymes may also decrease upon biochar application in contrast to other enzymes such as alkaline phosphatase [60]. Abiotic responses may likewise add to the concealment of soil CO_2 discharges. The biochar aided with alkaline metals and has high pH may precipitate CO_2 in the form of carbonates on the biochar surface [24, 62], 80]. Similarly, in the forest ecosystem, inorganic nitrogen governs the soil respiration and carbon mineralization. The reduction in root respiration upon biochar application can be either by decreasing root activities or by destroying the established roots. Despite the lack of live roots, soil CO_2 emissions with biochar alteration showed that variations in live root behaviour could not clarify the concealment of soil CO_2 outflows. The sustainable application of biochar can potentially offset as high as 12 % of human-induced CO_2 - C e emissions globally i.e., 1.8 of the 15.4 Pg CO_2 - C e yr^{-1} released, and that the cumulative net offset from biochar over ten decades will be 130 Pg CO_2 - C e. The biochar alterations in Miscanthus crop soil exhibited the ability to minimize soil CO2 eq emissions up to 33% on average over a couple of years and total soil CO_2 eq emissions were lowered by 37 % (main paper). Eventually, biochar application has been appeared to stifle or effectively affect soil CO_2 emanations, with a couple of remarkable exemptions in long term investigations [90, 124, 142].

The climate mitigation ability of biochar derived mainly from its extremely recalcitrant existence with under 1 % degradation of biochar after its application which delays the pace of fixed carbon return to the atmosphere [68]. The factors determining the carbon footprint of biochar include pyrolysis temperature, soil parameters, decay rate, the carbon intensity of the fuel as well as the type of biomass used [52]. Pyrolysis temperature assumes an indispensable function in the biochar mineralization and accordingly CO_2 outflow from the soil. Biochar synthesized at a temperature under 400°C animates C mineralization which diminishes with expanding pyrolysis temperature [155]. The pyrolysis temperature variations prompt noteworthy changes in physiochemical structure as well as composition liable for CO_2 emissions as found in few investigations [9, 12, 95, 112]. Moreover, the decay pace of biochar and eventually CO_2 discharge shift under fluctuating soil conditions, *viz.*, hydrological conditions, and local soil natural carbon content [66, 95]. The temperature at which biochar is synthesized and the nature of feedstock material decide the level of polarity (O/C ratio) just as the aromaticity (H/C ratio) of the synthesized biochar. Low H/C ratio and high H/C ratio show the nearness of a higher measure of labile C and subsequently more CO_2 discharge from the soil [65] and vice versa [28]. Subsequently, biochar can be utilized to remove more atmospheric CO_2 and its utilization can be a viable way to deal with the climate battle in the coming future.

Methane mitigation methodologies exhibit ecological, social, financial and food security significance in view of its high global warming potential, which is 25 times than of CO_2 over a century [132, 150]. The most significant natural, sources of CH_4 are characteristic wetlands (27%); fossil fuel derived products (18%); cattle ranching (18%); rice paddies (11%); termites (4%); and seas and hydrates (3%), and human-induced are burning of biomass (10%) and landfills (9%) [30]. A total of 151% increase in methane production have been recorded since industrial revolution (IPCC, 2007) [57], and is currently expanding at a pace of 3×10^{-3} m mol mol^{-1} yr^{-1} [17, 22], which is expected to rise further due to the growing global demands. According to FAO, (2008) [167] methane emissions by the end of 2050 are expected to rise exponentially with meat and dairy demands. Agriculture represents 10 – 12 % of cumulative worldwide anthropogenic greenhouse outflows which incorporates half of the total methane outflows [117]. While trying to relieve the antagonistic impacts of expanding CH_4 emanation, attempts have been made to limit methane outflows, fundamentally from anthropogenic destinations.

Methanogenic microbes under anaerobic waterlogged environment led to the emission of methane by a process known as methanogenesis. In contrast, aerobic ambient conditions favours methanotrophic bacteria particularly α- and γ-proteobacteria and also facultative methanotrophs of genera Methylocapsa and Methylocella responsible for methane reduction [67, 101]. The equilibrium between the two imperative microbial processes that too depends on soil physiochemical and biological parameters, determines the net methane transition between soil and the ambient environment. The products of the anaerobic disintegration of natural soil organic carbon and exogenous organic content serve as the substrate for methanogens (Dalal et al., 2008) which can however be inhibited by electron acceptors within the soil. Methane oxidation is an enzyme-dependent reaction performed via CH_4-assimilating bacteria and autotrophic NH_4-oxidizing bacteria by means of enzymes methane monooxygenase and ammonium monooxidase respectively, both of which require O_2 which is closely interrelated to soil texture and moisture content. In spite of the fact that methanotrophs can tolerate drastic acidic and saline conditions, their ideal operation usually happens within a relatively limited scope of pH 5.0–7.5. It ought to be noted that natural or fertiliser induced ammonium ion release in soil often presents competitive constraints to methane oxidation. Studies indicate that biochar influences these development processes by preventing the production of CH_4 through activities that include optimising soil diffusion of O_2 by soil moisture, soil compaction and soil fertility control. Biochar application purports to causes improved aeration and water content of soil, increase pH, decrease bulk density and increased CH_4 soil diffusion which eliminates anoxic conditions, which may forbid [107] or incite CH_4 oxidation [111, 122, 149, 152] or often both [34, 41, 104]. Mechanical drivers behind these processes are only assumed and mostly remains ambiguous. The suppression in CH_4 oxidation may likewise happen because of stifled microbial activity attributable to toxic or inhibitory compounds found in the biochar [122]. Biochar application can shorten the N cycle by restricting the accessibility of N substrates to microbial organisms, reducing CH_4 production, and thereby upholding methanotrophy. Likewise, biochar is also known to act as biofilter to boost methanotrophic methane utilisation under anoxic environments and hence cut methane emissions [41, 103]. However, few investigations reported that despite supressing N_2O emissions biochar application promoted a methane swapping scenario [64, 152].

N_2O is one of the most active (298 times than CO_2) greenhouse gases emitted from both natural and anthropogenic sources (3:2). Earthbound N_2O outflows have expanded from 10 – 12 Tg N_2O-N yr^{-1} in 1990 – 2000 and could exceed 16 Tg N_2O-N yr^{-1} by 2050 [166]. Because of the widespread use of engineered nitrogenic fertilizers, farming is the fundamental source (90%) of global anthropogenic N_2O emanation [47]. Even though few investigations depicted that N_2O is generated employing abiotic redox reactions, it is generated mainly by microbial transformations of reactive N in soil [11, 23, 109, 111, 133]. Besides, soil can serve as a source as well as a sink for N_2O. Bacteria of both autotrophic, as well as heterotrophic nature, are known to utilize N_2O, thereafter changing it to N_2 [27]. Two important cycles i.e., nitrification and denitrification, that drive evolution of N_2O and enhance N available to plants, is a successful procedure to diminish N losses [32, 92]. Many investigations have suggested that biochar use in agriculture fields could influence the transformations and fate of N [114, 136]. In addition, soybean and grass-covered biochar applied fields revealed a 50 – 80 % reduction in N_2O emissions [107]. Incitement and restraint of N_2O emanation by biochar relies on the underlying moisture content of the soil during the period of soil rewetting [147]. Nitrogen available to soil biota harbor organic and inorganic N species along with nitrate and ammonium, which are promptly used by biota [55]. Biochar is known to decrease the nitrogen that is accessible for denitrification as soil ammonium retention under biochar application is greatly enhanced [114, 126]. With biochar addition, the NH_4-N and NO_3-N content diminish hence N_2O emission [139]. The level of N_2O emission decrease under biochar application likewise relies upon the feedstock used, age, and pace of biochar utilized, conditions under which the pyrolysis was carried out, and also the soil type and its moisture content. Biochar produced from different feedstocks under varying temperature reigns [148] and its degree of application, reported a significant nitrate absorbing potential with the biochar synthesized at a higher temperature and also at higher application rate. Freshly prepared biochar use in low-inorganic nitrogen soils can immobilize considerable aggregate of inorganic nitrogen, restricting the substrate accessible to soil nitrifiers and denitrifiers for N_2O emanation [29, 131]. Moreover, pH, C: N ratio of the biochar applied also interferes with the soil N cycle by directly or indirectly governing the N turnover and hence N_2O release. The basic properties of biochar enhance the soil pH which facilitates the activity of enzymes *viz.,* N_2O reductase, and *vice versa* for reductases associated with the transformation of nitrite to N_2O *via* nitrate [147]. To accomplish a decrease in N_2O emissions, the C: N proportion of the feedstock ought to be $\geq$ 30 so the resulting biochar would induce immobilization of C and N, subsequently lessening the discharges. Thus, biochar properties relying on feedstock and pyrolysis conditions particularly C, pH, and NO_3 are the central participants in administering N_2O releases. The level of N_2O emissions is additionally affected by the aromaticity and stability of the oxidizable component of biochar followed by a slower deterioration of recalcitrant, steady fraction. Hypothetically, the proportion of nitrifiers to denitrifiers is influenced by biochar application in soil. Biochar can also prolong the deterioration of soil organic matter by-soil conglomeration, thus affecting aeration and at last N_2O emissions [83]. Via many interconnected pathways, biochar can influence N_2O development making it a test to define a particular system for mitigating N_2O. However, the impact of biochar on soil N_2O outflows is not generally certain.

Biochar and crop production

The observed repercussions on crop production diverge based on connexions among the nature of biochar applied, crop being examined, the soil type, ambient climatic and ecological factors, biochar ingredients, circumstances under which the biochar is generated, soil physicochemical and biological properties, and trial conditions. By and large, the effects of biochar on crop profitability are more articulated in well weathered supplement poor and acidic soils overwhelmed by clay mineral kaolinite and weathered products of Fe/Al-rich silicates i.e., sesquioxides as in humid tropics. In contrast, numerous other studies have indicated only minor improvements or even declines in grain yield with biochar formulations in supplement-rich soils [136] which might be because of the utilization of alkaline biochar that as of now have a high pH [164], immobilization of accessible N in the soil [20] and the existence of phytotoxic substances *viz*., heavy metals and PAHs in biochar, which may slow down plant growth. Although a few investigations have observed expanded harvest profitability from utilizing biochar alone (Chan *et al.,* 2009), several other experimental studies have noticed a more optimistic response when biochar is applied along with fertilizers [127]. A suitable proportion of biochar and synthetic fertilizer had reported to multiple the yield of *Oryzasativa* and *Sorghum bicolor*contrast with chemical fertilizer alone [127]. Mau and Utami (2014) [163] additionally reported an increment in the yield of *Zea mays* because of improved P accessibility and take-up under consolidated utilization of biochar and arbuscular mycorrhiza fungal spores.

The beneficial implications of biochar on crop production are typically ascribed to (a) direct accessibility of fundamental essential nutrients such as N, P, K, Ca, and Mg, from biochar applied [162]. An overall increase in the nitrogen was observed after the addition of biochar [160]. However, this does not mean that a lesser quantity of N fertilizer is required, as N in biochar is not accessible to plant biota; rather, it is mixed in the C matrix. Consequently, the ability of biochar to minimize fertilizer necessities stays muddled. (b) the alkaline effect induced by biochar application on acidic soils. Moreover [108] have attributed the boost of bean production due to the rise in soil pH besides soil nutrients due to biochar use. (c) improvement of soil CEC attributable to permeable nature and high surface area of biochar [161], (d) improving the physical state of soil by improved soil water-holding capability, decreased soil bulk density, and improved stabilization of soil structure. Collins (2008) [160] reported a noteworthy improvement in soil water holding limit on silt loam soils when compared to sandy soil. This might increase yield output in dryland regions that is often under water stress. Jeffery *et al.,* (2011) [58] also reported an overall limited but substantial positive change in yield upon biochar application, and described an increase in soil WHC besides an increase in soil pH as the key factors, (e) efficient nutrient use, [10], (f) stabilization of phytotoxic components in soils and elimination of their availability to plants [159], and (g) incitement of biological nitrogen fixation and nodulation [162] in legumes which may be due to elevated amounts of available [8], stimulatory impact on the development of nodules, available N immobilization, or increase in soil pH upon biochar addition [158], (h) slow release of essential nutrients, stability of higher organic matter and maintenance of ions (Lehmann 2007). These useful impacts of biochar may help to resolve land constraints, and can likewise have pertinence to land restoration and remediation [157].

II. CONCLUSION

The research has revealed that biochar is a sustainable tool to restore the degraded soil ecosystems. It has not only proved effective in management of soil but is considered as eco friendly technique as compared to synthetic fertilizers. Most of the studies have revealed substantial crop improvements by the use of biochar. Biochar has become a promising stabilizer in methane mitigation in agriculture sector and may help to reduce green house emissions as well.

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