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Review Article

Biochar Improves Soil Health, Crop Productivity and Reduces Greenhouse Gas Emissions - A Review

Sainath Nagula[1]*, A.V. Ramanjaneyulu[1], C Durga[2] and Naveen Leno[3]

[1]Professor Jayashankar Telangana State Agricultural University, Agricultural Research Station, Tornala - 502 114, Telangana, India
[2]Kerala Agricultural University (KAU), College of Agriculture, Thrissur - 680 656, Kerala, India
[3]Kerala Agricultural University (KAU), College of Agriculture, Vellayani - 695 522, Kerala, India

Abstract

Biochar produced by the thermo chemical degradation of biomass in a zero or limited oxygen environment through the process of pyrolysis. We made an attempt to review and discuss multifarious effects of biochar on crop production, soil physical, chemical and biological properties besides carbon sequestration and greenhouse gas emissions. Biochar act as a soil amendment thus crop growth and yield by retaining and supplying nutrients better than other organic materials such as leaf litter, compost and manure. Thus, it improves soil fertility, soil cation exchange capacity and biological nitrogen fixation. It reduces bulk density of soil providing a medium for adsorption of plant nutrients and improves conditions for soil micro-organisms and reduces soil degradation. It can effectively adsorb heavy metals such as lead which otherwise contaminate the soils. Conversion of biowaste into biochar, is a potential tool for reducing ill effects of global climate change.

Keywords: Biochar, soil health, remediation, greenhouse gas mitigation, carbon sequestration

***Correspondence**
Author: Sainath Nagula
Email: sainathnagula134@gmail.com

Introduction

Agriculture in any country produces huge quantity of crop residue. This is generally considered as a liability, because, easy and low-cost technology for conversion and utilization of this valuable asset is lacking. Among the cereal residues, rice, wheat and maize straw/stubble are the dominant. According to an estimate by Ministry of New and Renewable Energy (MNRE), Govt. of India, New Delhi, out of the total crop residue of 501.73 MT generated in India, nearly 18.5% (92.81 MT) is subjected to burning [1] (**Table 1**) and majority of the rest of the residue is fed to the cattle directly or as silage or hay and remaining may be incorporated in-situ or used for miscellaneous purposes.

Majority of the farmers have been heaping, burning and then conversion into ash in the field itself. But this traditional practice is leading to environmental pollution [2]. Further, burning of one tonne of rice straw accounts for loss of 5.5 kg nitrogen, 2.3 kg phosphorus, 25 kg potassium and 1.2 kg sulphur besides organic carbon [3]. Potential source of GHGs and other chemically and radiative important trace gases and aerosols such as CH_4, CO, N_2O, NOX and other hydrocarbons is burning of crop residues. Many of the pollutants in biomass smoke are suspected to be carcinogenic and could lead to various air borne/lung diseases [4]. To circumvent these problems, researchers could find biochar, a more resistant organic matter.

Biochar is a carbon rich, porous and fine grained product retined after pyrolytic conversion of plant biomass at high temperatures. It has the ability to improve soil fertility status. Further, due to its large surface area, it can retain more water and nutrients and supply the same to the crops [5]. The form and size of the feedstock and pyrolysis product may affect the quality and potential uses of biochar [6]. Pyrolysis temperature is the main regulating factor which governs surface area of biochar [7]. Biochar prepared at 600^{o}C had wider C:N ratio making it more stable in soil. Biochar produced from different feed stock had pH ranged from 8.2-13.0 and total carbon content from 33.0 to 82.4%. N and S compound tends to volatize at a temperature above 375°C [8]. The bulk density (BD) of wheat and rice biochar prepared at 400^{o}C was comparatively lower than the pearl millet and maize biochar. The water holding capacity (WHC) of wheat biochar was highest with 561% followed by maize biochar (456%) [9].

Table 1 State wise crop residue generated, residue surplus and burnt (Year, 2009) [4]

S. No.	States	Residue generation (Million tonnes)	Residue surplus (Million tonnes)	Residue burned (Million tonnes)
1	Andhra Pradesh	43.89	6.96	2.73
2	Arunachal Pradesh	0.40	0.07	0.04
3	Assam	11.43	2.34	0.73
4	Bihar	25.29	5.08	3.19
5	Chhattisgarh	11.25	2.12	0.83
6	Goa	0.57	0.14	0.04
7	Gujarat	28.73	8.90	3.81
8	Haryana	27.83	11.22	9.08
9	Himachal Pradesh	2.85	1.03	0.41
10	Jammu &Kashmir	1.59	0.28	0.89
11	Jharkhand	3.61	0.89	1.10
12	Karnataka	33.94	8.98	5.66
13	Kerala	9.74	5.07	0.22
14	Madhya Pradesh	33.18	10.22	1.91
15	Maharashtra	46.45	14.67	7.42
16	Manipur	0.90	0.11	0.07
17	Meghalaya	0.51	0.09	0.05
18	Mizoram	0.06	0.01	0.01
19	Nagaland	0.49	0.09	0.08
20	Orissa	20.07	3.68	1.34
21	Punjab	50.75	24.83	19.65
22	Rajasthan	29.32	8.52	1.78
23	Sikkim	0.15	0.02	0.01
24	Tamil Nadu	19.93	7.05	4.08
25	Tripura	0.04	0.02	0.02
26	Uttarakhand	2.86	0.63	0.78
27	Uttar Pradesh	59.97	13.53	21.92
28	West Bengal	35.93	4.29	4.96
	Total	501.73	140.84	92.81

Biochar production

Biochar production can be done in different ways with heating biomass with limited or zero oxygen to drive off volatile gases, leaving carbon behind [6]. The common biochar production processes involve slow and fast pyrolysis.

Slow pyrolysis is the most successful approach and produces biochar yield of 25-35%. However, it may vary depending on the nature of the feedstock, reactor type as well as the degree of operating conditions. In this method, the residence time of the feedstock is longer and the temperatures are lower than 700^{o}C. This allows all the volatile components to escape leaving a solid biochar behind. The pyrolytic gasification is an example of indirectly heated processes which utilizes an external vessel to burn portion of the fuel and uses the heat to pyrolyze the biomass producing medium energy gas with high fraction of tars. Such type of production design produce biochar has great possibility for modification because the movement of the ignition front leaves biochar behind [10].

Bio oil is produce by fast pyrolysis and the amount of biochar formed is a small fraction of nearly 12% of the total biomass. To obtain a high bio oil yield, biomass fast pyrolysis needs to satisfy four conditions namely, a medium temperature (450 - 600^{o}C), high heating rate (103 - 104 K s^{-1}), short vapour residence time (<2 s) and fast condensation of vapours [11]. This implies that although a series of biomass materials can be used to produce biochar, the yield largely depends on the method of production as well as the operating conditions. Such conditions include temperature, particle size, moisture content, feedstock type, nature or type of the reactor and mode of operation. The small scale technologies available can be either manually operated or automatically run. In these technologies, it is possible to control some of the variables that affect the yield of biochar while it is not possible to directly control some operating conditions. The mode of operation also varies with reactors designed for either autothermal or allothermal mode [11].

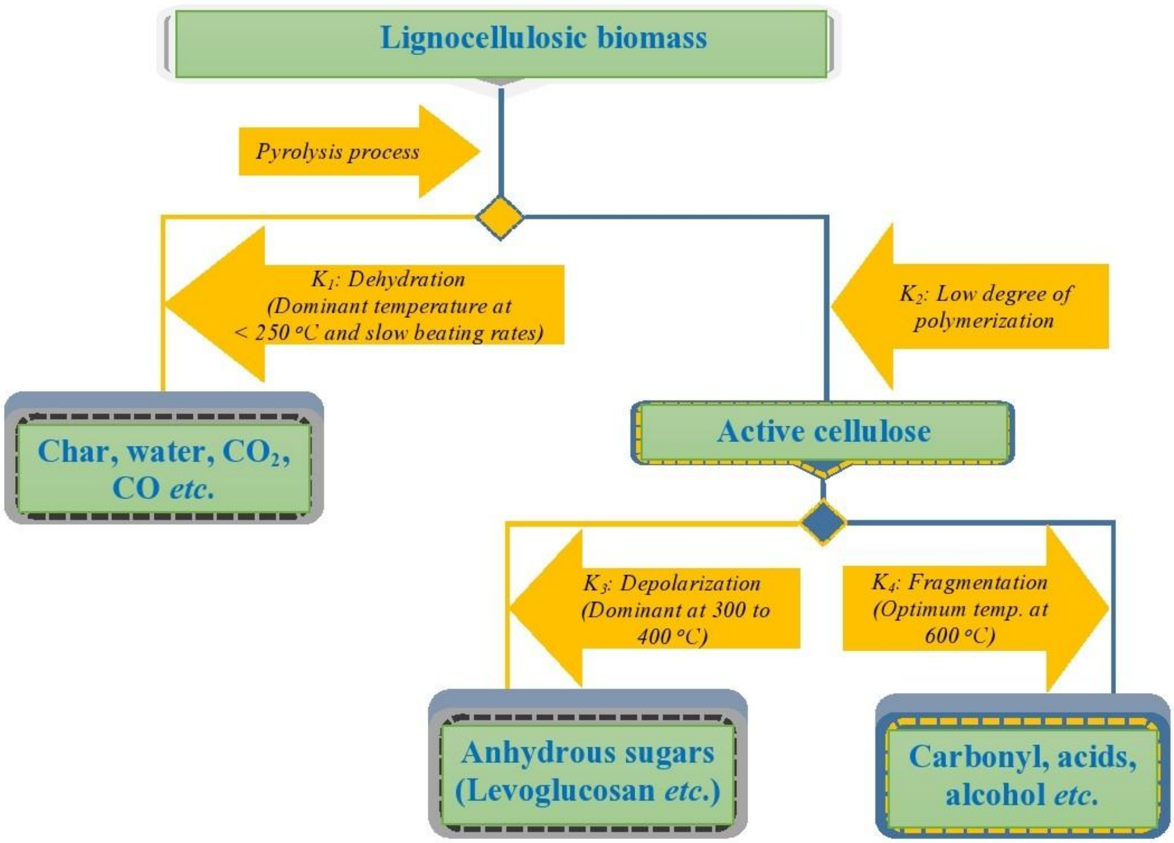

Figure 1 Waterloo-mechanism of primary decomposition of lignocellulose biomass [12]

Pyrolysis of biomass primarily consists of three stages *viz*., initial evaporation of free moisture, primary decomposition and secondary reactions that involve oil cracking and repolymerisation [13, 14]. In pyrolysis process, lignocellulosic biomass materials decompose on heating or exposure to an ignition source by two alternative pathways. First pathway is dominated by a temperature below 300°C and the second pathway is dominated by temperature above 350°C. First pathway finally produces a highly reactive carbonaceous biochar which involves elimination of water, carbonyl, carboxyl and hydroperoxide groups; formation of free radicals, reduction in the degree of polymerization by bond scission; evolution of CO and CO_2. Second pathway, which involves disproportionation and fission reactions molecules cleavage by a process called transglycosylation, to provide a mixture of tarry anhydro sugars and lower molecular weight volatile products [15]. The reaction pathway of cellulose pyrolysis is described as Waterloo-mechanism represented in **Figure 1** [14]. Biomass decomposition to solid char primarily takes place at 200-400^{o}C which is responsible for the largest degradation of biomass [16].

The production of biochar in modern industrial devices can be a highly controlled process with low gas emissions [17]. However, achieving the same results under rural tropical conditions, *i.e.,* with poorly maintained technologies in very low-income settings is more challenging [18]. Traditionally, earth mound or earth covered pit kilns have been used most frequently. They require very less investment hardly requiring some poles and sand to cover the pyrolyzing biomass. However, they are slow and time consuming [19] and generate significant gas/aerosol emissions [20]. Retort kilns involve a higher material investment and partially combust pyrolysis gases, reduce gas emissions by about 75% and have relatively high conversion efficiencies of 30-45% [21]. Biochar producing pyrolytic cook stoves such as TLUDs (Top Lit Up Draft) and Anila stoves [21] can generate biochar while providing heat for cooking. It's advantages include that they burn cleanly thus reducing indoor air emissions, can use various biomass residues as feedstock and are fuel efficient. Pyrolytic gases are mostly combusted in the flame front, reducing emissions of CO, CH_4 and aerosols by around 75% [22] compared to open fire or three stone cooking. Even though the epidemiological evidence behind the relationship between indoor air emissions and premature death rates is scant, this can be considered as an advantage. Though modern gasifier pyrolysis units are costly, but they have lowest emission factors and generate electricity [17]. A recent development has been the introduction of the Kon Tiki flame curtain kiln [23] which is fast compared to traditional kilns (hours instead of days), cost effective and easy to operate. Flame curtain kilns come in two basic concepts: as a conical, all steel deep cone bowl and as a simple soil pit, consisting of a conically shaped hole in the ground which can be dug in a few hours and is essentially free of investment cost.

The biochar produced from tender coconut husk had an alkaline pH (8.35), high total organic carbon 70.10 % and CEC 15.26 cmol kg^{-1}. Nutrient composition of the biochar is N 1.52 %; P 0.40 %; K 2.26 %; Ca 0.54 %; Mg 0.20 %; S 0.46 %; Fe 89.9 mg kg^{-1}; B 6.78 mg kg^{-1} and Mn 2.84 mg kg^{-1}. The heavy metal (Pb, Cd, Ni, Cr, Zn and Cu) content in the refined biochar was much below the maximum allowed threshold limits. C:N, C:P, C:S and C:N:P:S ratios were 46.11, 175.25, 259.62 and 350:7.5:2:1 respectively [24].

Biochar prepared from weed biomass such as *Ageratum conyzoides*, *Lantana camera*, *Gynura sp.*, *Setaria sp.*, *Avenafatua*, Maize stalk and Pine needle. Characterization of biochar revealed that biochar productivity ranged between 35.9 to 48.3 % on dry basis [25] (**Table 2**). Highest productivity of biochar was found from pine needles which may be due to uniform size of needles, while, lowest productivity of biochar with *Gynura sp.* However, only a little variation was observed in moisture content (8.1 to 11.2%) of produced biochar. It contained 75.7 to 83.8% total organic matter with highest in biochar from *Avenafatua* and lowest from maize stalks. Maximum total organic carbon (TOC) content was obtained in biochar from *Avenafatua* (54.2%) which was followed by *Setaria sp.* (55.2%), pine needles (54.6%) and *Gynaria sp.* (53.9 %). This produced biochar can be a potential source of soil carbon [25].

Table 2 Characteristics of biochar derived at 400°C for 4 hours from seven different source / biomasses [25]

S. No.	Source / biomass	Productivity *	Moisture content	Total organic matter	Volatile matter	Total organic carbon	Ash content
1	*Ageratum conyzoides*	38.7	10.1	78.8	26.2	52.6	21.2
2	*Lantana camera*	41.6	10.2	77.9	25.9	52.0	22.1
3	*Gynura sp.*	35.9	10.3	79.9	25.9	53.9	20.1
4	*Setaria sp.*	44.9	10.1	80.9	25.8	55.2	19.0
5	*Avenafatua*	45.5	8.1	83.8	27.5	56.2	16.3
6	Maize stalk	47.9	11.2	75.7	23.8	51.9	24.3
7	Pine needle	48.2	9.0	76.9	22.3	54.6	23.1

*Values are given in % on dry weight basis

Beneficial effects of biochar application

Soil quality and fertility improvement

The central quality of biochar that makes it attractive as a soil amendment is its highly porous structure which is potentially responsible for increased soil surface area and improved water retention. Because of its aromatic structure dominated by aromatic carbon, it has been found to be biochemically recalcitrant compared to uncharred, parent organic matter and thus can have enhance the long-term soil carbon pool [26].

Biochar application to soil leads to several interactions mainly with soil matrix, soil microbes and plant roots [27]. The rates and types of interactions depend on different factors such as composition of biomass as well as biochar, methods of biochar preparation, physical characteristics of biochar and soil environmental condition mainly soil temperature and moisture. Biochar can act as a soil conditioner by improving the physical and biological properties of soils such as bulk density and aggregate stability [28] water holding capacity, soil P retention [29] and also enhancing plant growth [7]. Application of biochar to in-fertile soils decreases soil bulk density, increases total pore volume (16.3%) and water holding capacity (5.9 to 25.5% field capacity) [30]. Presence of biochar in the soil mixture influences the physical characteristics such as structure, texture, soil consistency and porosity with changing the pore size distribution, surface area, density and packing. Thus, biochar effect on soil physical properties may have a direct effect on plant growth because the penetration depth and availability of air and water within the root zone [25].

The results revealed that the application of biochar @ 10 kg $plant^{-1}$ coupled with 75% as per STBR (Soil Test Based Fertilizer Recommendation) enhanced the physical properties of the soil by imparting 57.11% increase in the water holding capacity (WHC), 35.32% increase in porosity, 7.31% decrease in the bulk density (BD) and 55.9% enhancement in soil dehydrogenase activity [31].

As an amendment

Activated char the carbonaceous materials received considerable attention in recent years as soil amendment for both releasing essential nutrients like sulphur and sequestering heavy metal contaminants [32]. Currently lacking information on how aging affect the integrity of biochar as soil amendment for both environmental remediation and agricultural purposes [28]. Biochar has a relatively structured carbon matrix with a medium-to high surface area, suggesting that it may act as a surface sorbent which is similar in some aspects to activated carbon. They have a strong affinity to non-polar substances such as polycyclic aromatic hydrocarbons (PAHs), dioxins, furans (PCDD/Fs), Polychlorinated biphenyls (PCBs) and Polybrominated diphenyl ethers or PBDEs and a high surface to volume ratio. Biochar can be used by farmers to control and reduce the soil pH and also lime applications [28].

Nitrate leaching

Nitrogen is an essential nutrient and plays an important role in increasing crops yields and its quality. Hence, the nitrogen in form of nitrate, ammonium, or urea (which rapidly hydrolyses to ammonium) is widely used to increase the crops yields. NO_3^- is not adsorbed by the negatively charged colloids compared to ammonium and it dominates most soils. Therefore, nitrates ions can move downward freely with the drainage water and are thus readily leached from the soil. Such leaching losses will cause serious environmental problems [32, 33]. Thus, nitrogen became a resource of pollution. Biochar was used to prevent such leaching losses of nitrates. Biochar has the ability to retain nitrogen (N) within soil and enhance ammonia (NH_3), ammonium (NH_4^+) and NO_3^- adsorption [34], thus making these N sources unavailable for nitrification or NO_3^- leaching. The effects of sugarcane bagasse charcoal produced at 800^{o}C on nitrate leaching and found that it was able to reduce the leaching of nitrate from a calcaric dark red soil by 5% when applied at a rate of 10% (w/w) [35]. Reduction in leaching is attributed to mainly physical adsorption of the nitrate and water by the micro porous biochar. The reclamation efficacy of three soil amendments, *viz*. humic acid, water residual treatment and biochar are compared on leaching of nutrients in a silty loam soil in USA [36, 37]. Biochar can reduce mean cumulative leaching of total organic carbon (TOC) by 30%, nitrite by 34% and nitrate by 33% as compared to control, likely due to sorption by the biochar. Biochar treatment showed the highest value of soil microbial biomass C:N ratio, and one possible reason might be that biochar could decease the fraction of biomass N mineralized [38].

Heavy metals

Crop productivity is seriously affected by abiotic stresses such as soil salinity and heavy metal contamination [39, 40]. A number of mechanisms may play a role in controlling the removal of heavy metals from aqueous solutions by biochar, including physical sorption, complexation, precipitation, ion exchange and electrostatic interaction [41]. Biochar have negatively charged on surfaces and can sorb positively charged metals ions by electrostatic attractions. Specific ligands and functional groups on biochar can also interact with various metals to form complexes [42]. A number of studies have reported the positive effects of biochar under either heavy metal [39, 43] or salt stress [44]. Compared to organic amendments biochar was more effective in reducing Cd uptake by wheat plants [5]. Similarly, biochar application increased growth, photosynthesis and potato yield under salt stress while it decreased the Na^+ and increased the K^+ content in the xylem [44]. The biochar in combination with plant growth promoting bacteria increased maize growth and biomass and decreased the Na^+ and increased the K^+ content in xylem sap of maize (44%) [45]. Lower Na concentration was found in leachates from columns treated with biochar compared to the non-biochar-treated columns [46].

Soil enzyme activity

Microbially produced extracellular enzymes are important for decomposition of organic matter and cycling of nutrients for microbial as well as plant uptake. Biochar, with its capacity to absorb a wide range of organic and inorganic molecules, may affect enzymes by sorbing them and/or their substrates [47, 48]. The effects of biochar on four soil enzymes *viz*., βglucosidase, N-acetyl-β-glucosaminidase, lipase, and leucineaminopeptidase showed that biochar had inconsistent and unpredictable effects on soil enzymes [47]. In addition, microbial properties and enzyme activities are dynamic and highly sensitive to environmental change and thus changes in these properties might indicate potential long-term effects of biochar on soil nutrient cycling processes. Biochar effect on different soil properties detailed in **Table 3**.

Crop productivity

Directly or indirectly biochar application improves crop yield. Biochar produced after pyrolysis contains higher amount of nutrients than the biomass from which they are prepared shows direct effect. Biochar application causes an indirect effect due to improvement in soil physical, chemical and biological properties. Biochar application at the rate of 30 tones ha^{-1} in combination with FYM and nitrogen improved yield components of maize crop [55]. Biochar application @ 30 t ha^{-1} in combination with mineral nitrogen @ 75 kg ha^{-1} is recommended for improving maize productivity [55]. Agegnehu et al. [56] revealed that the combination of biochar along with compost is found to be more effective in improving the soil properties and crop yield than biochar alone. In sandy acidic soils, conservation farming and biochar amendment is found to be a promising combination for increasing harvest yield. Several workers have reported that biochar applications to soils have shown positive responses for net primary crop production, grain yield and dry matter [57] (**Table 4**). Biochar application reduced the oxidative stress and increased the bean growth under salt stress [58].

Table 3 Effect of biochar on different soil properties

S. No.	Factor	Impact	Reference
1	Cation exchange capacity	50 % increase	[49]
2	Bulk density	13 % decrease	[37]
3	Specific surface area	15 % increase	
4	Fertilizer use efficiency	10-30 % increase	[50]
5	Liming agent	1point pH increase	[51]
6	Methane emission	100 % decrease	[52]
7	Nitrous oxide emissions	50 % decrease	[53]
8	Mycorrhizal fungi	40 % increase	[50, 54]
9	Biological nitrogen fixation	50-72 % increase	[51]

Table 4 Summary of experiments assessing the impact of biochar addition on crop yield

S.No.	Study outline	Results summary	References
1	Comparison of maize yields between disused charcoal production sites and adjacent fields, Ghana	Grain and biomass yield were 91% and 44% higher on charcoal site than control (2.36t ha^{-1} and 1.14t ha^{-1} respectively)	[59]
2	Pot trial on radish yield in heavy soil using commercial green waste biochar (three rates) with and without N	Application of biochar 100 t ha^{-1} increased yield thrice linear increase from 10 to 50 t ha^{-1}	[60]
3	Enhanced biological N_2 fixation by common beans through biochar additions, Colombia	Bean yield increased by 46% and biomass production by 39% compared to control at 90 and 60 g biochar kg-1, respectively	[52]
4	Mitigation of soil degradation with biochar. Comparison of maize yields in degradation gradient cultivated soils in Kenya.	Maize grain yield doubling in the highly degraded soils from about 3 to 6 t ha-1 (80g biochar kg^{-1})	[61]
5	Four cropping cycles with rice (*Oryza sativa* L.) and sorghum (*Sorghum bicolor* L.)	Charcoal amended with chicken manure amendments resulted in the highest cumulative crop yield (12.4 t ha^{-1})	[62]

Carbon sequestration and climate change mitigation

Biochar used as a soil amendment is to sequester the carbon in order to mitigate climate change; numerous studies addressed the microbial response to biochar addition in terms of emissions of the greenhouse gases N_2O, CO_2 and CH_4 from soil [63]. Agriculture contributes about 58% of the total anthropogenic emissions of N_2O, and this amount is estimated to increase by 35-60% by 2030 due to increased nitrogen (N) fertilizer use and increased animal manure production [64].

Carbon sequestration

Soil C sequestration is the removal of atmospheric CO_2 through photosynthesis to form organic matter, which is ultimately stored in the soil as long-lived, stable forms of C [65]. Terrestrial, atmospheric, ocean, and geological are the important pool of carbon. Varying life time is seen in the carbon with in these pools, and flows take place between them all. Carbon in the active carbon pool moves rapidly between pools [6]. Passive pool contains stable or inert carbon. Carbon flows from the active pool to the passive pool by biochar so it decreases carbon in atmosphere. Biomass organic matter converted into stable C pools by controlled carbonization which is assumed to persist in the environment over centuries [49]. Biomass carbon to biochar conversion leads to 50% sequestration of the initial carbon compared to the low amounts retained after burning (3%) and biological decomposition (<10-20% after 5-10 years) [6]. Carbon sequestration potential of various feed stock like forest residue, mill residues are 0.021 and 0.024 Gt C $Year^{-1}$ as furnished in **Table 5** [66].

Table 5 Carbon sequestering potential of various feedstocks [66]

S. No.	Feed stock	CSP (Gt C $year^{-1}$)
1	Forest residues	0.021
2	Mill residues	0.024
3	Rice husk	0.038
4	Groundnut shells	0.038
5	Urban waste	0.038
6	Agricultural and forest residues	0.16

Mitigation of greenhouse gas emissions

Burning of residues emits a significant amount GHGs. For example, on burning N (2.09%) in straw is emitted as N_2O. In rice straw 70, 7 and 0.66% of C present is emitted as CO_2, CO and CH_4, respectively [18]. 3 kg particulate matter, 60 kg CO, 1460 kg CO_2, 199 kg ash and 2 kg SO_2 releases by burning of one tonne straw [60, 67]. Semi-volatile organic compounds (SVOCs) including polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs), SOx, NOx, volatile organic compounds (VOCs) and other light hydrocarbons are also emitted. These gases may lead to a regional increase in the acid deposition, levels of aerosols, increase in tropospheric ozone and depletion of the stratospheric ozone layer [18, 68].

Reduction of N_2O and CH_4 emission as a result of biochar application is seen to attract considerable attention due to the much higher global warming potentials of these gases compared to CO_2 [62, 69]. A 50% reduction in N_2O emissions from soybean plots and almost complete suppression of CH_4 emissions from biochar amended acidic soils in the Eastern Colombian Plains [52]. Reduction of N_2O emissions by biochar amendment was observed in field experiments and confirmed by meta-analyses across laboratory and field studies [70]. Additions of 15 g biochar kg^{-1} of soil to a grass and 30 g kg^{-1} of soil to a soil cropped with soybeans completely suppressed methane emissions [52]. Application of rice straw biochar decreased the cumulative CH_4 and N_2O emissions from paddy soil significantly by 64.2%-78.5% and 16.3%-18.4%, respectively in rice [71]. The biochar and biochar compost based soil management approaches can improve SOC, soil nutrient status and SWC, and maize yield and may help mitigate greenhouse gas emissions. Biochar amendments significantly reduced N_2O emissions both in the field and the laboratory experiments, significantly decreased CO_2 emissions from paddy field but increased CO_2 emissions from both upland fields and laboratory incubations. The suppression of soil CO_2 emissions may be due to reduced enzymatic activity and the precipitation of CO_2 onto the biochar surface [72, 73]. The biochar can potentially offset a maximum of 12% of current anthropogenic CO_2-C equivalent emissions to the atmosphere (*i.e.* 1.8 Pg emissions can be avoided out of the 15.4 Pg of CO_2-C equivalent emitted annually), decreasing significantly the emissions of carbon dioxide by preventing decay of biomass inputs [74, 75]. Moreover, it has been suggested that biochar presence in soil might initiate a positive feedback wherein soil physical and chemical properties are improved and plants yields increased as a result; this feedback further enhancing the amount of CO_2 removed from the atmosphere [75]. Furthermore, biochar suppresses the emissions of other GHGs, such as nitrous oxide and methane (both significant agricultural pollutants and far more harmful in their radiative forcing impact than CO_2). Emissions of greenhouse gases such as CO_2 and N_2O, which are 300 times more potent than CO_2, were significantly reduced in soils [50, 66, 75] indicating that biochar could play an important role in removal of carbon from the atmosphere which is increasingly recognized as essential to meeting global climate targets. Biochar application for environmental management can be motivated for soil improvement, waste management, energy production and climate change mitigation [25].

Biochar status in the world and India

Pyrolysis and biochar production technologies at household level have been developed in the countries like Belize, Cameroon, Chile, Costa Rica, Egypt, Kenya, Mongolia and Vietnam [76]. Small scale production units and biochar stoves developed in these countries aim to assess the environmental, economic, social and cultural costs and benefits of introducing biochar technology and use of biochar for soil fertility improvement and reducing environmental degradation. Further, in India, the ICAR-Central Research Institute for Dryland Agriculture (CRIDA) developed biochar kiln to produce biochar using feed stocks of maize, cotton, castor and pigeon pea crop residues, on a small scale and certain parameters like loading rate, maximum conversion efficiency and holding time were standardized for all the four bio-residues [8].

Two, non-governmental organization (NGOs) viz., Arti and Janadhar, in collaboration with RaGa LLC are pioneering decentralized biochar production using modular pyrolysis kilns in villages and small towns in India using waste biomass, bagasses and organic municipal solid waste [8]. However, meagre efforts were made to upscale the technology across the globe.

Conclusions and future perspectives

Conversion of crop biomass into biochar is based on the concept of 'Waste to Wealth' and has the potential to eliminate the need for burning crop residues thereby environmental pollution. It conserves soil organic carbon and nutrients, improves water holding capacity, nutrient supplying ability, soil fertility, quality and crop productivity. It reduces greenhouse gas emissions and enhances carbon sequestration. Further research is required to identify most suitable location specific and economical feed stock with high conversion efficiency across all agro-climatic zones. Further, most important and urgent need to investigate its' potential in improving the soil health and productivity in organic production systems. As its usage in negligible in India, and rest of the world, efforts must be made to encourage its production and usage.

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