Chapter 2
Utilizing Agricultural Waste in Production of Biochar for Improving Soil Properties and Increasing Crop Yield Through Field Application

Mahendra Pratap Choudhary, H. D. Charan, and Biswajit Acharya

Abstract Management of agricultural waste has recently become a grave problem in India. The technological advancement and farm mechanization have resulted into improved crop production, but simultaneously, in the absence of practical and economic options, the farmers prefer to burn the agricultural waste in open fields which creates environmental threats in terms of emission of greenhouse gases responsible for environmental and human health hazards. The direct burning of agricultural waste also deteriorates the soil quality as well as results in loss of biomass and soil microbes leading to reduced crop yields. This burning of agricultural waste (locally known as *Parali*) in the adjoining states of Delhi is presumed to be one of the reasons for dense smog and very high air pollution in the national capital region of New Delhi after Kharif season in the months of October to November every year for quite some time. The concerned governments, the National Green Tribunal (NGT) and Hon'ble Supreme Court of India are constantly monitoring over the issue and have put it on utmost priority to find out a permanent solution of this recurring problem. With the objective of finding out an optimum solution of the problem, a novel indigenous method has recently been found out in which the disposal of agricultural waste is ensured in an eco-friendly manner by converting it into a useful product, known as biochar. The biochar has great potential in mitigating air pollution and, when applied to soils, can help in upgradation of soil properties and increased yield of the crops. The concept behind the innovation is that of the thermal conversion, in which the crop residues are subjected to pyrolysis either in little presence or absence of oxygen. The most significant feature of the method is its adaptability. The farmers can convert their agricultural waste into biochar at the fields, and the biochar so produced can be further applied to the soils for upgrading the soil properties that ultimately helps to increase the crop

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production. This novel method of producing biochar is very simple and does not require much investment and technical skills.

Keywords Agricultural waste · Biochar · Soil improvement · Crop yield

2.1 Introduction

Agriculture is the backbone of Indian economy as more than two-thirds of the Indian population is involved in some way or the other with the agriculture and associated activities. Indian farmers are nowadays making use of modern technology and farm machinery for increased crop production and faster harvesting. This has resulted into yet another issue of agricultural waste management. In order to prepare their fields for the upcoming crops, the Indian farmers usually adopt the practice of stubble burning. Due to unawareness of the modern methods of waste management and the time and resources required therein, the farmers prefer to burn the large quantities of crop residues in the fields itself. The new age harvesters and mechanical crop cutters cut and collect the useful upper half portion of the crops such as wheat, mustard and paddy and leave behind the bottom half parts in the form of stalks. As the farmers get very less time in between two crop seasons for field preparation for the upcoming crops, they burn the crop residues directly in the open fields. This practice not only saves a lot of time but also the money otherwise required to invest on clearing the fields manually or mechanically. There are some other motives of the crop residue burning in the field such as shortage of laborers and unavailability of residue buyers (Kaur 2017). At first instance, this practice may be seen as a faster and cheaper one, but in broader aspects, it proves to be very harmful for the human and the animals, the soil biota and the environment as a whole. Inappropriate clearance of biomass produced by the agricultural sector is a major environmental threat all over the world (Siddiqui et al. 2017). The burning of agricultural waste produces harmful greenhouse gases such as CO_2, CO, CH_4 and oxides of nitrogen (Gupta et al. 2004) which eventually emit in the atmosphere and cause long-term environmental impacts.

The annual incidences of very high levels of air pollution and smog during October to December months in the national capital region of New Delhi, for some years in the recent past, are allegedly known to occur because of this crop residue burning in the nearby adjoining states of Punjab, Haryana, Rajasthan, Uttar Pradesh and Madhya Pradesh (Kumar and Singh 2020). Although, way back in the year 2015, the National Green Tribunal (NGT), New Delhi, had already banned the open burning of the crop residues, leaves and such any other materials releasing noxious contaminants into the ambient atmosphere, the farmers are yet not complying it in its true sense. The gravity of the situation can be realized with an instance when the city of New Delhi observed the most dangerous state of air quality index, i.e. worst category during winter 2017 when the fine particulate matter ($PM_{2.5}$) was observed at the maximum concentration ever at 640 μg m^{-3} (ETB 2017) as compared to the allowable value of 40 μg m^{-3} as per the Indian national standards on ambient air quality (NAAQS 2009).

Bhuvaneshwari et al. (2019) discussed the issue of crop residue burning in India highlighting the socioeconomic roots behind the cause rather than agricultural or waste management concerns. They discouraged the solutions entailing high capital investments in terms of infrastructural requirements or costly technologies. The authors insisted on sustainable way-outs for crop waste minimization and utilization in the form of generating biogas and biochar as well as in situ management. More intensified mechanization in harvesting had been recommended to adopt along with subsidized provisions by the government so that the farmers can be encouraged. Kumar and Singh (2020) reviewed the responsible factors behind burning the crop residues by the farmers in India and proposed the alternatives in terms of the socioeconomic sustainability of the farmers. They concluded that in spite of burning the crop residue in fields, it must be used for production of biogas, biochar and bioethanol or as a fuel in thermal power plants.

Hence, it can be realized very well that the crop residue burning in open agricultural fields is against the established environmental norms as it burns useful biomass and at the same time gives access to harmful gases into the atmosphere. Therefore, looking to the severity and recurring incidences of stubble burning, a simple, cheaper and viable answer to the problem has been found out. An innovative way of converting the abundant crop residues into a useful product called biochar has been revealed. This method not only helps the farmers in solving the problem of clearing their agricultural fields well in time but also assists in reducing the atmospheric pollution and increasing the productiveness of the soils by stabilizing them and at the same time sustainably managing the huge amounts of crop residues.

2.2 Biochar Production

It is believed that the Amazonians first produced and used charcoal (biochar) for improving their nutrient-poor soils around 2500 years ago. They discovered to produce biochar by first igniting the biomass, then burying it in ground (or earth) and finally leaving for smoldering in the absence of oxygen. This method can be called as slash-and-char which results in carbon sequestration up to 50%, whereas the method adopted by modern farmers in India is a type of slash-and-burn which results in only 1–3% of carbon sequestration, and a high amount of ash is produced. The term biochar was first coined by Peter Read in 2005 (Godbey 2016) to illustrate a material that looks almost similar to charcoal, but that is actually carbonized biomass converted into a solid material, used to enhance functions of soil and lessen emissions of greenhouse gases. One of the earliest studies proposed the use of biochar into soils as a new method to set up a considerable and lasting storage for atmospheric CO_2 in terrestrial ecosystems (Lehmann et al. 2006).

A carbon-rich product, biochar is attained through a method known as pyrolysis. This method involves heating of biomass or other organic substances at temperatures above 250 °C either in the little presence or absence of oxygen (Lehmann 2007). The researchers are showing increased interest in biochar during the last decade because

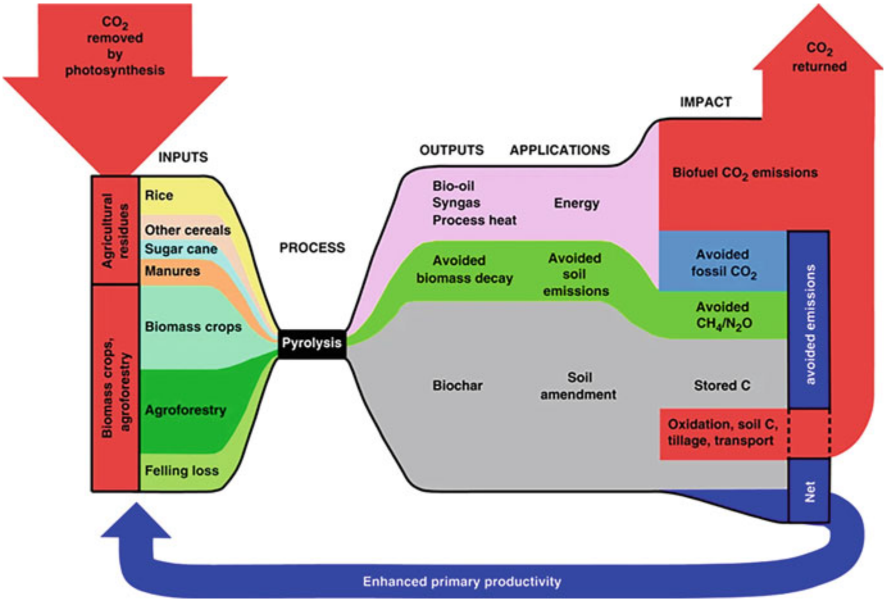

Fig. 2.1 Flowchart showing sustainable biochar concept (Woolf et al. 2010)

of its potential scope in multidisciplinary areas like mitigating climate change as well as potential for soil amendment and sustainable farming (Lehmann et al. 2011).

The concept of sustainable biochar is represented in Fig. 2.1, which shows inputs, process, outputs, applications and impacts on global climate. The height/width of the different coloured fields represents the relative proportions of individual components of each category (Woolf et al. 2010). The process starts from the removal of CO_2 from the atmosphere by photosynthesis to yield biomass. Out of this total biomass, a fraction consisting of agricultural residues, biomass crops and agro-forestry products is converted through a process called pyrolysis into biochar, bio-oil, syngas and process heat. The bio-oil and syngas are further used to get energy through combustion. This energy and the process heat generated as above are used to offset fossil carbon emissions (Woolf et al. 2010).

The biochar produced acts to store carbon for a very long period as compared to the case when biomass would have not been converted to biochar and left for decay on its own. During the process, CH_4 and N_2O emissions are significantly avoided by way of skipping natural decay of biomass. The biochar can be used to amend soils, and the CO_2 returned to the atmosphere is less in comparison to the originally produced by direct combustion of the biomass. Thus, biochar acts as carbon-negative. Another simple explanation in terms of flowchart for producing biochar through pyrolysis is shown in Fig. 2.2 in which we can see that biomass is used for production of biochar and bio-energy generation and 50% of the carbon is returned back to the soil as carbon sequestration.

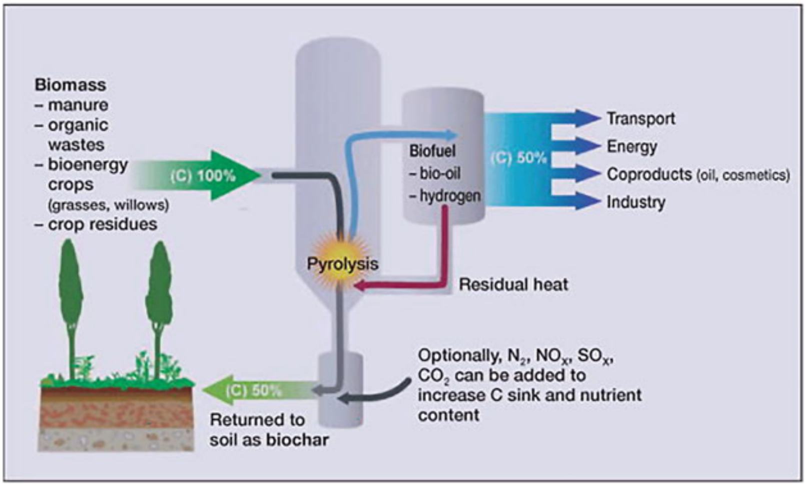

Fig. 2.2 Flowchart showing biochar production technology (Lehmann 2007)

The production methods of biochar have changed a lot over the centuries, but the principles have remained the same. These days biochar is produced in a complete eco-friendly manner through the processes called pyrolysis, gasification and hydrothermal conversion in which biomass is heated anaerobically and all the emissions are captured in the closed system and subjected to re-burn or broken down into less harmful elements, hence preventing the release of CO_2 and other GHGs into the atmosphere.

The simplest method of producing biochar is the thermal decomposition of the biomass because traditionally biomass has primarily been the raw material used to produce biochar. Biomass consists of biodegradable portions of the products, wastes and residues from agriculture, forestry and other allied agro-industries and biodegradable municipal waste also. There are two basic approaches for the production of biochar. The ancient approach consisted of either earthen pits or mounds in which the wood was piled and covered with the earth itself. Then it was burned slowly with a limited amount of air. The method is still used in some of the developing countries to make charcoal, but it produces considerable smoke and also releases CO_2 and other GHGs into the atmosphere. The modern approach is based on the concept of pyrolysis, and both small-scale and large-scale productions of biochar are carried out using biochar stoves, ovens or kilns and large industry setups. Countries like Japan, China and Australia have innovated small pyrolysis ovens which help to dispose of domestic waste and produce biochar for small gardens. The bigger size stoves can be converted into portable units so that they can be used at the site of biomass and hence transportation costs can be minimized. For large-scale production of biochar, pyrolysis reactors are established at such places where other infrastructural facilities are easily available.

Biochar can be produced from a variety of biomasses such as agricultural wastes, organic wastes, forest residues, bioenergy crops, kitchen wastes and sewage sludge having diverse physical and chemical characteristics (Nartey and Zhao 2014). It can also be produced from other waste materials like manure and green wastes which may otherwise produce even more obnoxious greenhouse gases when resorted to disposal by open burning (Lehmann and Stephen 2015). Therefore, it is advantageous to utilize such leftover materials in a more productive way. For a very long time, the production and storage of biochar in soils has been proposed as a means of climate change mitigation through carbon sequestration, providing energy and increased crop production (Woolf et al. 2010). A large number of foreign researchers are working on the aspects of biochar production and its use for soil amendment (Barus 2016; Carter et al. 2013; Ding et al. 2016; Fryda and Visser 2015; Gokila and Baskar 2015; Parmar et al. 2014; Tammeorg et al. 2016); nevertheless, there are only a few significant evidences of research on biochar in India, being comparatively a novel thought in terms of making use of crop residues for producing biochar and its application as soil amendment.

2.2.1 **BioCharan*: An On-Site Method of Biochar Production***

Occurrence of a large number of crop residue burning incidences in India and the vacuum of a suitable technological solution easily adoptable by the farmers were the two actual inspirations to carry out the study (Choudhary et al. 2021a). A novel method named *BioCharan* has been developed for converting the crop residues into biochar. The method clears the agricultural fields for upcoming crops on the one hand, while, on the other hand, it helps in reducing the environmental pollution, stabilizing the field soils as well as problematic expansive soils and enhancing the physical and chemical properties of soils and eventually the yield of crops. Hence, it proves to be a perfect step towards attaining the sustainable development (Choudhary et al. 2021b). This method is an economic and feasible one as it does not require any technical skills to operate and an individual farmer can convert the residues into useful product biochar to resolve the problem of crop residue disposal and environmental air pollution through emission of greenhouse gases during crop residue burning. The studies carried out so far and available in the literature point out towards using biochar to enhance the agronomic parameters of soils related to improvement in crop yield and soil fertility. This review is supposed to be one of the leading reviews of its kind in India wherein application of biochar has been used to study the effect on geotechnical characteristics of the soils. By understanding the concept of conventional methods of biochar production and then applying some indigenous wisdom, it was considered to produce biochar at the field level through a modified kiln made up of a cylindrical empty diesel drum. Looking to the absence of any cost-efficient alternative in Indian scenario, the farmers can produce biochar using this novel method of *BioCharan*, and the biochar produced can be further utilized in the fields for increasing the soil fertility (Choudhary et al. 2021c).

(a) (b) (c)
(d) (e) (f) (g)

Fig. 2.3 (**a**) Drum filled with *mustard* crop residues; (**b**) burning on fire at the bottom; (**c**) drum covered with a top lid and left for 15–20 min for pyrolysis to take place; (**d**) raw biochar produced; (**e**) biochar crushed into small pieces; (**f**) applying biochar in agricultural field; (**g**) collecting soil sample

Figure 2.3 shows various steps of on-site biochar production applying the drum method and its field application as well as collection of soil samples.

A cylindrical drum having both ends open with 3 ft height and 2 ft diameter has been utilized to make biochar from crop residues. The drum is supported on stones or bricks so that limited entry of air can be ensured from the bottom end. The drum is then filled up with the crop residues, and, once filled, it is ignited at the bottom. After ignition, the residues are allowed to burn only for 2–3 min, and the supporting stones or bricks are taken away, and the drum is covered at the top with a lid. The crop residue inside the drum is hence allowed to convert into biochar through heating process for a period of about 10–15 min. The drum is then detached from its position when it becomes cool, and the raw biochar is collected and crushed into smaller parts so as to mix with soil samples either for laboratory experimentation or for field trials.

A drum can process crop residues of about 15–20 kg at a time. Therefore, it is advisable to use five to six such drums at the same time so that about one quintal of agricultural waste can be transformed into biochar at an instance, i.e. 15 min. In this way, one ton of crop residues can be produced in about 3 h. The overall cost of converting the crop residues into biochar comes out in the range of Rs. 4–5 per kg considering the costs involved in cutting of the residues up to the final production of biochar (Choudhary et al. 2021d). Hence, the production cost of biochar is quite less as the method does not necessitate any expensive equipment or technical skills.

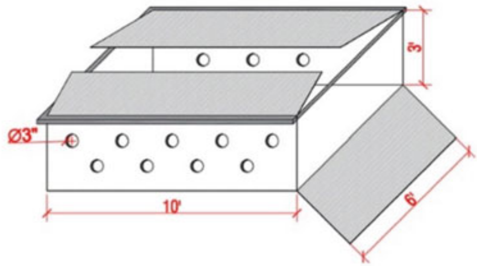

Fig. 2.4 Three-dimensional view of the *biochar trolley*

The volume of the drum is approximately 9.43 cubic feet (0.27 m^3) only which is quite less, and proper compaction is also required during filling up; otherwise, voids will remain in it. In this way, a large number of drums are required simultaneously to convert the available crop residues into biochar. Therefore, to further optimize the method of *BioCharan*, a modified design of tractor mounted trolley has been proposed as shown in Fig. 2.4. The conventional tractor trolley has the dimensions of 10′ × 6′ × 1.5′ which has been proposed to have new dimensions of 10′ × 6′ × 3′, i.e. only the height of the trolley has been increased so as to double the volume of the trolley without causing any other practical hindrances in its operation. The volume of the modified trolley is 180 cubic feet (5.09 m^3) which is approximately 19 times more than that of the drum. Hence, it increases the rate of conversion of crop residues into biochar and proves very economical as compared to the drums. The bottom face of the trolley is provided with two circular openings having adjustable covers/caps of 1 foot diameter so as to allow easy collection of raw biochar directly beneath the trolley.

This trolley acts as a *biochar trolley* as and when required; otherwise, it is a normal trolley with double the capacity of the conventional tractor trolley. The other modifications include provision of small holes of 3″ diameter having caps on both the sides of the trolley at suitable intervals so as to facilitate easy escape of smoke and gases during the process of pyrolysis, if required. To convert the trolley into a closed system, provision of top cover has been suggested in the form of additional sliding walls of 3′ height on both sides so that, when required, they can be raised above to close the trolley at the top. During normal functioning, the top cover splits into two-halves and stands inside the side walls and hence does not cause any obstruction.

2.2.2 Soil Preparation and Experimental Setup

In an experimental study, the soil samples were collected from fields, wrapped in polythene bags and taken to the soil testing laboratories for further processing where they were prepared as per the methods and procedures prescribed by the Bureau of Indian Standards (IS: 2720 1983). At the outset, the soil samples were placed in thermostatically controlled oven for drying, then pulverized and finally sieved through 4.75 mm size sieves. The particle size analysis, soil classification and other soil characteristics were found out as per the relevant IS standards. The soil type was classified as CI (inorganic clay having intermediate plasticity) according to the Indian Standard Soil Classification System (Choudhary et al. 2022). All relevant experiments were carried out in the laboratories to work out the outcome of mixing biochar on the physicochemical and engineering properties of the soil. The samples of soil were mixed with varying proportions of biochar by weight (% w/w) starting with minimum 5% and then increasing in its multiples up to maximum 25%. The biochar was added to soil in dry form ensuring that both are mixed thoroughly.

2.2.3 Biochar Characterization

Xie et al. (2016) summarized the biochar characteristics produced from different feedstock and identified the potential of biochar to maintain soil quality and sequester carbon. They analysed the biochar properties in reference to the sources of biochar considering elemental compositions, pH, surface area and cation exchange capacity. They found biochar technology as the right approach for neutralizing carbon resulting from carbon storage by itself and in reducing the GHG emissions, including CO_2, CH_4 and N_2O. The authors concluded that biochar exhibited huge probability for extended use in environmental fields; nevertheless, added continuing field trials are necessary to assess biochar application rates.

2.2.3.1 Physicochemical Characteristics and Particle Size Distribution

The characterization of biochar produced using *BioCharan* method when carried out by analysing physicochemical parameters as well as particle size distribution is shown in Table 2.1.

2.2.3.2 Elemental Analysis

The CHN analysis of biochar sample is shown in Fig. 2.5. The major elements found in biochar were carbon (45.421%), hydrogen (1.839%) and nitrogen (1.095%), whereas the other minor elements like sulphur and oxygen were not found. Hence, the CHN analysis confirms that biochar samples are carbon-rich.

2.2.3.3 FTIR Spectroscopic and SEM Analysis

The FTIR spectrum shows the functional groups present in a sample. The FTIR imaging of biochar is shown in Fig. 2.6. The biochar sample has more than five

Table 2.1 Important physicochemical characteristics of biochar and soil (Choudhary et al. 2022)

S. No.	Characteristics	Biochar	Soil
1	pH	9.56	7.62
2	Specific gravity	1.84	2.56
3	Moisture content (%, at 105 °C)	16.94	11.12
4	Electrical conductivity (mS cm^{-1}, at 25 °C)	9.65	4.23
5	Organic carbon (%, as OC)	1.86	0.56
6	Organic matter (%)	2.24	0.98
7	*Particle size distribution (%)*		
	(a) 2–4.75 mm	23.6	5.4
	(b) 0.425–2 mm	43.4	17.0
	(c) 0.075–0.425 mm	30.0	27.2
	(d) 0.002–0.075 mm	2.0	26.8
	(e) <0.002 mm	1.0	23.6
8	*Consistency limits (%)*		
	(a) Liquid limit	–	43.12
	(b) Plastic limit	–	24.25
	(c) Shrinkage limit	–	17.63
	(d) Plasticity index	–	18.87
9	*Geotechnical properties*		
	(a) Optimum moisture content (%)	–	16.00
	(b) Maximum dry density (g cm^{-3})	–	1.64
	(c) Water-holding capacity (%)	–	32
	(d) Unconfined compressive strength (kg) cm^{-2})	–	1.68
	(e) California bearing ratio (%)	–	1.96
	(f) Free swell index (%)	–	39

peaks indicating that biochar is not a simple element. The spectrum shows C–H, O–H and N–H as well as S=O, C=C and O–Si–O stretching and bending vibrations in the range of 3727 to 457 cm^{-1} indicating the existence of various functional groups like phenolic, hydroxyl, methyl, methylene, alkane, alkyl and silica.

The scanning electron microscopic (SEM) analysis of biochar in Fig. 2.7 shows the spectroscopic image of biochar obtained from mustard waste biomass.

The SEM analysis is helpful in demonstrating that biochar has porous and permeable structure besides large surface area. These characteristics are responsible for increased water-holding capacity and nutrient uptake.

2.2.3.4 XRD Analysis

The XRD image helps to determine the crystalline phases in a mixture by comparing with position and intensity of reference patterns. The XRD analysis of biochar is shown in Fig. 2.8. The peaks in XRD pattern indicate the presence of graphite, SiO_2,

Fig. 2.5 CHN analysis for biochar sample

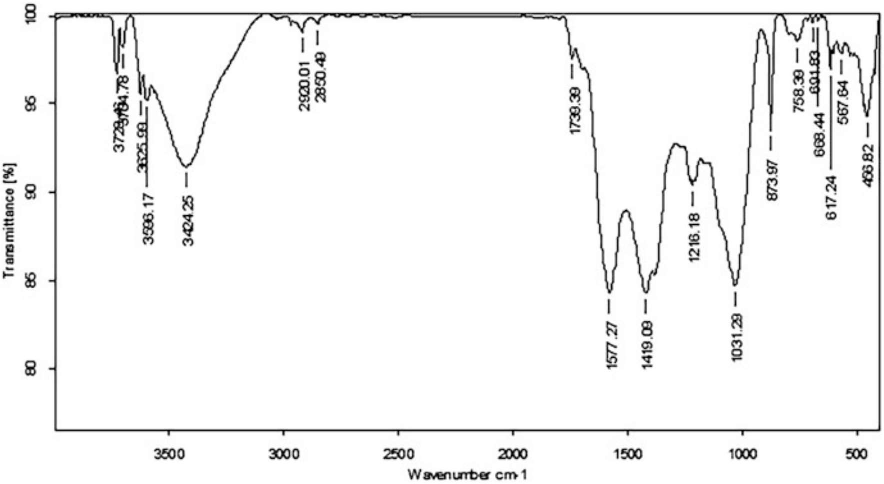

Fig. 2.6 FTIR spectroscopic image for biochar sample

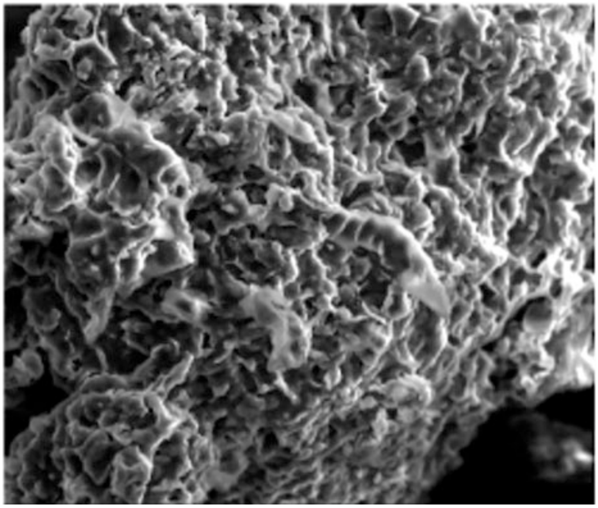

Fig. 2.7 SEM image of mustard biochar (Lucaci et al. 2019)

CaO and MgO. Hence, it can be concluded that biochar sample has a heterogeneous surface.

2.2.3.5 Physicochemical and Geotechnical Properties

The physicochemical properties of biochar as well as physicochemical and geotechnical properties of soil are represented in Table 2.1.

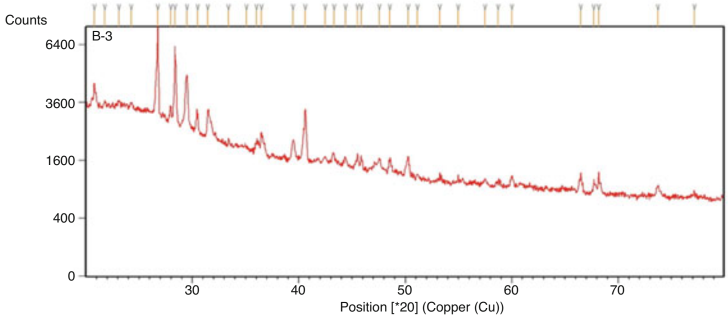

Fig. 2.8 XRD image for biochar sample

2.3 Effect of Biochar on Soil Properties

Reddy et al. (2015) studied the variation in the physicochemical and geotechnical properties of soil amended with varying proportions of biochar having different particle sizes. This study was found as the first of its kind in literature which considered geotechnical properties of the soil into account, and as per the results presented, soils amended with biochar were possessing improved geotechnical parameters to serve as stable landfill cover materials. Sadasivam and Reddy (2015) evaluated engineering properties of soils like compressibility and shear strength amended with biochar by using different types of seven biochars derived from wood. It was found that soil porosity, water-holding capacity and organic matter increase, whereas specific gravity decreases when biochar amendment is done. The shear strength of the soil also increases significantly by adding the biochar. Overall, the results were found quite encouraging in improving the soil properties.

Ding et al. (2016) reviewed the potential of biochar to improve soil fertility. It was observed that large surface area and nutrient content are the main characteristics of biochar. The authors discussed the effect of type of feedstock, pyrolysis temperature, pH, rate of application and different soil types along with mechanism behind the adsorption of nutrients by biochar. It was concluded that the negative effects reported by some studies and research gaps as well as uncertainties should be verified through further relevant investigations, especially long-term experiments. Alghamdi et al. (2018) performed an experiment to assess the impact of biochar combined with bentonite and compost with different application rates on physical and chemical characteristics of sandy soil. It was found that biochar and bentonite resist biodegradation in the soil and stay there for an extended time, whereas compost overcomes the negative impacts of chemical properties of soil.

Rajagopal et al. (2018) analysed the forecast of biochar in climate change mitigation with respect to Indian agriculture. The authors opined that biochar technology is in an emerging phase in India and still requires a general adoption by the farmers to take advantage of carbon sequestration, GHG offset, improved soil health and enhanced crop yields. They insisted for improved methods of biochar production because the costs involved in collecting and transporting the residues restrict the adaptation. The authors suggested that biochar technology has more potential for soil carbon sequestration over the conventional methods of residue management in reference to Indian agriculture.

Mohan et al. (2018) conducted an experimental study by using two biochars made from rice husk and corn stover and observed that water-holding and cation exchange capacities and organic carbon increased, while carbon dioxide emissions decreased. The soil fertility and crop growth were also observed. The authors suggested that the problem of agricultural biomass burning in India can be resolved if it is pyrolysed to get biochar, and when biochar is applied to soils, it will not only improve soil properties but will also act as a carbon sink. However, they also insisted on large field trials for prolonged time to ensure the long-term benefits.

The biochar application to soil improves the physiochemical characteristics of soil due to its richness in organic carbon that makes the soil more fertile and acts as a carbon sequester. Biochar decreases the denitrification potential and lowers N_2O emission, greatly controlling leaching of mobile nutrients such as potassium and hence improving water use efficiency, nutrient availability and plant growth (Panwar et al. 2019).

A number of experiments and laboratory tests indicate that there are positive effects of adding biochar on the physicochemical and engineering properties of the soil. The initial parameters of virgin soil without mixing biochar were determined, and then different proportions by weight (% w/w) of biochar like 5%, 10%, 15%, 20% and 25% in dry condition were added to the soil sample, and the soil-biochar mix was thoroughly mixed. Various parameters of virgin soil and that of the soil amended with biochar are represented in Table 2.2 (Choudhary et al. 2022).

The results indicate that mixing of biochar to soil increases the organic carbon, organic matter, moisture content and water-holding capacity and at the same time decreases the specific gravity and density of the soil. The mechanism responsible for this improvement is the formation of macroaggregates in due course of time resulting in enhanced interparticle cohesion and improved resistance to slaking.

The consistency limits of soil-biochar mix have changed upon addition of biochar to it. The liquid limit of the soil increased from 43.12 to 48.75% (13.06% higher) upon addition of biochar at the rate of 25%. The increase in liquid limit is due to high porosity and large surface area of the biochar. The plastic limit of the soil also increased from 24.25 to 28.65% (18.14% higher) which can be attributed to greater water-holding and water-absorbing abilities of biochar. Similarly, the rise in shrinkage limit is seen from 17.63 to 21.85% (23.94% higher) which indicates towards higher void ratio in biochar as compared to the soil, and hence more water is required to change from solid state to semisolid state.

The Proctor test was used to learn about the compaction characteristics of soil-biochar. The value of maximum dry density (MDD) of the soil, i.e. 1.64 g cm^{-3}, decreased to 1.42 g cm^{-3} as the biochar was added to it. The probable reasons for reduction in MDD are the low specific gravity of biochar as compared to the soil. The value of optimum moisture content (OMC), i.e. 16.00%, increased up to 17.32% on addition of biochar which indicates that biochar has absorbed moisture from the

Table 2.2 Physicochemical and engineering properties of soil amended with biochar

S. No.	Characteristics	Values for soil amended with biochar (BC)						% Variation
		Virgin soil	Soil +5% BC	Soil +10% BC	Soil +15% BC	Soil +20% BC	Soil +25% BC	
1	pH	7.62	7.67	7.69	7.73	7.72	7.80	*2.36*
2	Specific gravity	2.56	2.54	2.53	2.52	2.52	2.51	*−1.95*
3	Moisture content (%)	11.12	11.48	11.85	12.38	12.82	13.22	*18.88*
4	Electrical conductivity (mS cm^{-1})	4.23	3.97	4.15	4.32	4.39	4.42	*4.49*
5	Organic carbon (%)	0.56	0.57	0.62	0.69	0.72	0.72	*28.57*
6	Organic matter (%)	0.98	1.01	1.04	1.06	1.07	1.07	*9.18*
7	Water-holding capacity (%)	32	36	38	40	42	44	*37.50*
8	Liquid limit	43.12	44.42	45.26	46.74	48.34	48.75	*13.06*
9	Plastic limit	24.25	25.43	26.12	27.28	28.45	28.65	*18.14*
10	Shrinkage limit	17.63	18.65	19.27	20.12	21.47	21.85	*23.94*
11	Plasticity index	18.87	18.99	19.14	19.46	19.89	20.10	*6.52*
12	Optimum moisture content (%)	16.00	16.42	16.93	17.12	17.24	17.32	*8.25*
13	Maximum dry density (g cm^{-3})	1.64	1.58	1.48	1.45	1.43	1.42	*−13.41*
14	Unconfined compressive strength (kg cm^{-2})	1.68	1.74	1.79	1.82	1.86	1.94	*15.48*
15	California bearing ratio (%)	1.96	2.06	2.12	2.17	2.22	2.31	*17.86*
16	Free swell index (%)	39	38	36	32	28	27	*−30.77*

soil. The value of California bearing ratio (CBR) increased from 1.96 to 2.31% (17.86% higher) upon addition of biochar to the soil sample. The increasing values of CBR show that addition of biochar to soil has affirmative effect on the bearing capacity of the soil and demonstrates to be an apt amendment for the soil (Choudhary et al. 2022).

Overall, it is observed that for the soil-biochar mix, the organic carbon increased by 28.57%, moisture content by 18.88%, water-holding capacity by 37.50%, unconfined compressive strength by 15.48% and CBR value by 17.86% and free swell index decreased by 30.77% on addition of biochar. Biochar is a marketable bioproduct which can be used in agriculture, industries and energy sector. Biochar can be transported easily, and it is cost-effective as compared to fertilizer. Also, it lasts longer on application to soil (Oni et al. 2019).

2.4 Effect of Biochar on Crop Yield

Nguyen et al. (2015) selected wheat and corn crops to study the effects of different ways to return biomass on soil and crop yield by taking two materials, one as the wheat and corn straw and another one as biochar made from them. The results demonstrated that biochar was capable of significantly improving the cation exchange capacity and organic matter in the soils. The direct application of straws showed poor results and had no contribution in increasing the crop yields. However, it promoted the plants to absorb nutrients. The application of biochar alone showed better results than that of the straws alone. Shareef and Zhao (2017) overviewed the basics of biochar as a tool for soil improvement and provided guidelines for the farmers and gardeners about biochar, its use and benefits so as to ensure enhanced yield and quality of crops. The authors anticipated that biochar improves the physical and chemical properties by way of raising water-holding capacity of soil and absorbing nutrients to decrease leakage and augmenting the soil structure due to large surface area and porosity of biochar. They concluded that fertility of soil and crop yields can be improved if proper application rate of biochar is maintained.

To study the effect of biochar application on yield of crops, three crops of bajra (pearl millet), wheat and mustard were chosen, and biochar was applied into the fields at different rates of 10, 20 and 30 t/ha for three consecutive seasons. It was observed that the yields of crop increase on addition to biochar into the fields. Table 2.3 shows the variation in crop yields.

It can be seen that the yields of bajra, wheat and mustard increase in all the three seasons in the range of 10.34–16.39%, and the maximum yield has been observed during the second season. When biochar is applied for the first time into fields, it takes some time to get adapted to soils and then absorbs micronutrients, holds water and other soil microbes in its pores and releases them when required by the plants during their growth. Hence, the maximum effect is observed during the second season, and, as time passes, some of the biochar gets flooded with water, and their

Table 2.3 Crop production during different seasons

S. No.	Name of crop	Crop production during	Crop produced (in q/ha) at the rate of application of biochar				*% Increase in yield*
			Without biochar	10 t/ha	20 t/ha	30 t/ha	
1	Bajra	First season	18.5	19.4	20.5	20.9	*12.97*
		Second season	18.3	19.2	20.6	21.3	*16.39*
		Third season	18.0	18.8	19.9	20.4	*13.33*
2	Wheat	First season	18.0	18.6	19.5	20.3	*12.78*
		Second season	17.8	18.6	19.7	20.5	*15.17*
		Third season	18.2	19	19.8	20.4	*12.09*
3	Mustard	First season	20.0	20.8	21.7	22.4	*12.00*
		Second season	19.7	20.6	21.9	22.8	*15.74*
		Third season	20.3	20.9	21.8	22.4	*10.34*

storage of nutrients and water starts diminishing, whose effect can be seen during the third season. Therefore, it is suggested to apply biochar into the fields after every 2 years so as to maintain the sufficient quantity of biochar in soils.

Rani et al. (2018) reviewed biochar as a boon for agriculture. According to them, the use of biochar for soil and agricultural improvement is an age-old known fact as per the benefits identified in the existing literature. There are environmental advantages also, but there are still some grey areas which need clarity like application rate, effects of feedstock and soil types and conditions. The authors suggested long-term field studies so as to optimize biochar application to ensure crop yields and a common recognition by the farmers. Biochar has numerous advantages and can be used in reducing the tensile strength of the soil, increasing pH and soil structure and increasing the efficiency of fertilizer use (Sun et al. 2012).

2.5 Conclusions

This paper provides a review of the available production methods of biochar and its further application to soils for improving the physicochemical and geotechnical properties. It can be concluded that biochar can be produced economically and efficiently at the fields by adopting the novel method of *BioCharan.* The agricultural waste and other crop residues can be utilized for producing biochar. Further application of biochar in soils has shown several environmental and economic paybacks. Soil properties have shown positive results upon addition of biochar in different proportions. The important geotechnical properties of soils including Atterberg's limits, MDD, OMC, swelling characteristics, unconfined compressive strength and CBR value have improved on addition of the biochar. Therefore, biochar application shows a promising potential for resolving the recurring nuisance of high air pollution in northern India, especially in the Indian capital city New Delhi due to crop residue burning in the nearby states. And, finally, *BioCharan* method can be called a multi-benefit method wherein the problem of crop residue burning is resolved by converting it to produce biochar, improvement in soil properties and increase in crop production can be ensured by way of applying biochar to soils and most importantly the environmental air pollution is minimized because there is no crop residue burning. Hence, the only thing required is to create awareness about this method among the stakeholders and encourage them to adopt it.

References

Alghamdi Abdulaziz G et al (2018) Impact of biochar, bentonite, and compost on physical and chemical characteristics of a sandy soil. Arab J Geosci 11:670

Barus J (2016) Utilization of crops residues as compost and biochar for improving soil physical properties and upland rice productivity. J Degrad Min Lands Manage 3(4):631–637

Bhuvaneshwari S et al (2019) Crop residue burning in India: policy challenges and potential solutions. Int J Environ Res Public Health 16:832. https://doi.org/10.3390/ijerph16050832

Carter S et al (2013) The impact of biochar application on soil properties and plant growth of pot grown lettuce (*Lactuca sativa*) and cabbage (*Brassica chinensis*). Agronomy 3:404–418. https://doi.org/10.3390/agronomy3020404

Choudhary MP et al (2021a) A novel approach for disposing agriculture waste, minimizing air pollution and amending soil through biochar production and application. Nat Environ Pollut Technol 20(1):421–427. https://doi.org/10.46488/nept.2021.v20i01.026

Choudhary MP et al (2021b) Potential of biochar derived from crop residues in soil remediation and controlling air pollution due to stubble burning. Indian J Environ Prot 41(2):207–212

Choudhary MP et al (2021c) Converting agricultural waste into biochar for improving physical properties of soil. In: Patel S, Solanki CH, Reddy KR, Shukla SK (eds) Proceedings of the Indian Geotechnical Conference 2019. Lecture notes in civil engineering 134. Springer, Singapore. https://doi.org/10.1007/978-981-33-6370-0_10

Choudhary MP et al (2021d) Experimental investigation on biochar production and application: solution to air pollution due to stubble burning as well as amending soil consistency. J Inst Eng Ser A 102(3):705–712. https://doi.org/10.1007/s40030-021-00548-7

Choudhary MP et al (2022) A novel method of on-site biochar production from crop residues and further application to soils for improvement in soil characteristics. In: Satyanarayana Reddy CNV, Saride S, Krishna AM (eds) Ground improvement and reinforced soil structures. Lecture notes in civil engineering. 152. Springer, Singapore. https://doi.org/10.1007/978-981-16-1831-4_44

Ding Y et al (2016) Biochar to improve soil fertility: a review. Agron Sustain Dev 36:36. https://doi.org/10.1007/s13593-016-0372-z

ETB (Economic Times Bureau) (2017) Odd-even plan for five days in Delhi from Monday. https://economictimes.indiatimes.com/news/politics-and-nation/odd-even-plan-for-five-days-in-delhi-from-monday/articleshow/61575418.cms. Accessed 29 May 2022

Fryda L, Visser R (2015) Biochar for soil improvement: evaluation of biochar from gasification and slow pyrolysis. Agriculture 5:1076–1115. https://doi.org/10.3390/agriculture5041076

Godbey H (2016) Biochar: a brief history. https://www.permaculturenews.org/2016/11/18/biochar-brief-history/. Accessed 29 May 2022

Gokila B, Baskar K (2015) Influence of biochar as a soil amendment on yield and quality of maize in Alfisols of Thoothukudi district of Tamil Nadu, India. Int J Plant Anim Environ Sci 5(1):152–155

Gupta PK et al (2004) Residue burning in rice-wheat cropping system: causes and implications. Curr Sci India 87(12):1713–1715

IS 2720-Part 1 (1983) Methods of test for soils – preparation of dry soil samples for various tests (second revision) (reaffirmed May, 2020). Bureau of Indian Standards, New Delhi

Kaur A (2017) Crop residue in Punjab agriculture-status and constraints. J Krishi Vigyan 5(2):22–26. https://doi.org/10.5958/2349-4433.2017.00005.8

Kumar P, Singh RK (2020) Selection of sustainable solutions for crop residue burning: an environmental issue in north western states of India. Environ Dev Sustain 23:3696. https://doi.org/10.1007/s10668-020-00741-x

Lehmann J (2007) Bio-energy in the black. Front Ecol Environ 5:381–387

Lehmann J, Stephen J (2015) Biochar for environmental management: science, technology and implementation, 2nd edn. Routledge, London

Lehmann et al (2006) Biochar sequestration in terrestrial ecosystems-a review. Mitig Adapt Strateg Glob Chang 11:403–427. https://doi.org/10.1007/s11027-005-9006-5

Lehmann J et al (2011) Biochar effects on soil biota–a review. Soil Biol Biochem 43(9):1812–1836

Lucaci AR et al (2019) Potential use of biochar from various waste biomass as bio sorbent in Co (II) removal processes. Water 11:1565. https://doi.org/10.3390/w11081565

Mohan D et al (2018) Biochar production and applications in soil fertility and carbon sequestration–a sustainable solution to crop-residue burning in India. RSC Adv 8:508–520

NAAQS (National Ambient Air Quality Standards) (2009) Central Pollution Control Bureau, India. http://www.moef.nic.in/sites/default/files/notification/Recved%20national.pdf

Nartey DO, Zhao B (2014) Biochar preparation, characterization, and adsorptive capacity and its effect on bioavailability of contaminants: an overview. Adv Mater Sci Eng 2014:1. https://doi.org/10.1155/2014/715398

Nguyen T-H et al (2015) Effects of different ways to return biomass on soil and crop nutrient contents. Nat Environ Pollut Technol 14(3):733–738

Oni BA et al (2019) Significance of biochar application to the environment and economy. Ann Agric Sci 64:222–236. https://doi.org/10.1016/j.aoas.2019.12.006

Panwar NL et al (2019) Comprehensive review on production and utilization of biochar. SN Appl Sci 1:168. https://doi.org/10.1007/s42452-019-0172-6

Parmar A et al (2014) Biochar production from agro-food industry residues: a sustainable approach for soil and environmental management. Curr Sci 107(10):1673–1682

Rajagopal V et al (2018) Prospects of biochar in climate change mitigation in Indian agriculture–an analysis. Int J Agric Sci 10(9):5905–5910

Rani P et al (2018) Biochar: a boon for agriculture. Int J Chem Stud SP4:86–93

Reddy Krishna R et al (2015) Effects of biochar amendment on geotechnical properties of landfill cover soil. Waste Manag Res 33(6):524–532. https://doi.org/10.1177/0734242X15580192

Sadasivam BY, Reddy KR (2015) Engineering properties of waste wood-derived biochars and biochar-amended soils. Int J Geotech Eng 9(5):521–535. https://doi.org/10.1179/1939787915Y.0000000004

Shareef TME, Zhao BW (2017) The fundamentals of biochar as a soil amendment tool and management in agriculture scope: an overview for farmers and gardeners. J Agric Chem Environ 6:38–61

Siddiqui MTH et al (2017) Characterization and process optimization of biochar produced using novel biomass, waste pomegranate peel: a response surface methodology approach. Waste Biomass Valorization. https://doi.org/10.1007/s12649-017-0091-y

Sun K et al (2012) Polar and aliphatic domains regulate sorption of phthalic acid esters (PAEs) to biochar. Bioresour Technol 118:120–127

Tammeorg P et al (2016) Biochars in soils: towards the required level of scientific understanding. J Environ Eng Landsc Manag 25(2):192–207. https://doi.org/10.3846/16486897.2016.1239582

Woolf D et al (2010) Sustainable biochar to mitigate global climate change. Nat Commun 1:56

Xie T et al (2016) Review of the effects of biochar amendment on soil properties and carbon sequestration. J Hazard Toxic Radioact Waste 20(1):04015013. https://doi.org/10.1061/(ASCE)HZ.2153-5515.0000293