Converting Agricultural Waste into Biochar for Improving Physical Properties of Soil

M. P. Choudhary, H. D. Charan, and Biswajit Acharya

Abstract Biochar is a carbon-rich, fine-grained, porous material obtained from pyrolysis process, in which biomass is subjected to thermochemical conversion in the absence of either oxygen or very little oxygen. India is currently facing an acute problem of management of large quantities of agricultural waste which is either partially utilized or unutilized due to certain constraints. One of the indiscriminate uses of crop residues adopted by Indian farmers in the states of Punjab, Haryana and Uttar Pradesh is direct burning in open fields (in the form of *Parali*) which causes emission of greenhouse gases in the atmosphere. It is one of the sources of air pollution being faced every year during winter in the national capital region of Delhi. One of the recent advancements to combat this problem is the conversion of agricultural waste into biochar and applying it back into the soils to improve soil properties. Although biochar is not a new product, it has recently drawn attention of researchers because of its usefulness in improving the soil properties and as a means of carbon sequestration, thereby reducing greenhouse gas emission. Direct burning of agricultural wastes in fields cannot be called an environmental-friendly approach as it causes loss of biomass as well as introduces harmful gases into the environment. So converting agricultural wastes into biochar may be a better solution. In India, not much research has been carried out so far on biochar application in soils. The process of making biochar and the effects of utilizing biochar on the physical properties of soil have been presented in this paper, which will prove useful for Indian context where large quantities of agricultural waste are produced that creates environmental air pollution when directly burnt in fields.

Keywords Biochar · Agricultural waste · Greenhouse gases · Physical properties of soil · Carbon sequestration

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1 Introduction

Agriculture is the main source of livelihood for about 60% of the Indian population, and at the same time, it is known to be the third largest source of greenhouse gas emissions, following the burning of fossil fuels and transportation [1], and in near future, the developing world as a whole is expected to witness an upsurge in the growth of agro-processing industry, and there will be a need to manage the waste generated from these industries. The agricultural and related agro-industries waste has the potential to supply feedstock for biochar production. Converting residual biomass into biochar can help in achieving long-term carbon sequestration and other beneficial effects on soils [2].

Biochar, a carbon-rich product, is obtained by heating biomass in the absence of or with a limited amount of oxygen at above 250 °C. This process is known as charring or pyrolysis which is also used for making charcoal. However, biochar is different from charcoal or other carbon products in that it is intended for use as a soil amendment [3]. Biochar has gained a great deal of attention in recent past due to its chemical and physical properties and has been portrayed as one of the potential drivers of climate change mitigation and sustainable agriculture [4]. Biochar is inspired by the fascinating properties of ancient Terra Preta, found in Amazon basin. It has been identified as a soil amendment and has very specific properties of adsorption and stability that make it unique among organic soil amendments [5].

The annual outburst of smog reportedly witnessed for last 3–4 years in the months of October–November in the national capital region of New Delhi is known to occur due to open burning of agricultural wastes by the farmers of nearby states like Haryana, Punjab, Uttar Pradesh and Rajasthan. During this period, the city witnesses the worst level of air quality, when the concentration of fine particulate matter ($PM_{2.5}$) is observed at the highest levels ever, e.g., at 640 $\mu g/m^3$ [6] against the annual permissible limits of 40 $\mu g/m^3$ as per the national ambient air quality standards of India [7].

After yielding the crops like wheat, rice or mustard from agricultural fields, generally the Indian farmers adopt the age-old practice of burning the wastes in their fields to clean up and prepare the fields for next crop as it is a fast, easy and cheap method of disposing off the wastes. Though the National Green Tribunal (NGT, New Delhi) has imposed a complete ban in 2015 on burning of crop residues and other materials which emit toxic pollutants into the atmosphere [8], farmers are still practicing it because they are unaware of the fact that it is harmful to their fields as it causes loss of biomass which may help positively in crop yield. So, there is a need for spreading awareness among the farmers regarding safe disposal of agricultural wastes in terms of biochar production. Figures 1, 2 and 3 show the burning of agricultural waste in fields near Kaithoon area of Kota district in Rajasthan.

The beneficial features of biochar are governed by the physical properties of the biochar which are altogether different from the physical properties of the soil and hence could change the physical properties of the soil also, if soil is amended with biochar [9].

Fig. 1 Crop residue of mustard plants after crop yield near Kaithoon, Kota, Rajasthan

Fig. 2 Crop residue put on fire by farmers near Kaithoon, Kota, Rajasthan

Fig. 3 Agricultural field after burning the waste near Kaithoon, Kota, Rajasthan

Furthermore, locally available weed biomass is an important source for preparing the biochar as it is not economically important as well as causes crop loss due to its presence. If biochar is prepared from the locally available weeds, then it can reduce the weed population in the agricultural fields on the one hand, and on the other, it can enhance plant growth by improving the physical, chemical and biological characteristics of soil, all contributing to increased crop production and productivity [10].

2 Biochar Production

Biochar is produced by heating organic substances under conditions of incomplete oxygen [11]. Biochar can be produced either at individual farms or at large industrial setups [12], making it applicable for a large number of socioeconomic situations. Different types of pyrolysis technologies are commercially available that yield different proportions of biochar and bioenergy products, such as bio-oil and syngas [12]. The pyrolysis of biomass can be carried out in a reactor via gasification or carbonization at varying temperature and time depending on the final intended use of the end product [13].

Biochar can be made from a wide range of biomasses having different physical and chemical properties. Extensive feedstock biomasses have been used in the production of biochar such as bio-energy crops, forest residues, organic waste, agricultural waste, kitchen waste and even sewage sludge also [14].

For Indian conditions, biochar can be produced by individual farmers in their fields in conventional kilns made by locally available material or at community kilns by using the agricultural wastes and other by-products, so that the biochar produced can be utilized again for applying in the fields for the upcoming crops. To produce biochar from agricultural waste, a drum of 220 L capacity has been used as shown in Figs. 4, 5 and 6.

3 Materials and Methods

3.1 Biochar

The biochar produced as above at the field level from agricultural waste is crushed to small pieces, air-dried and passed through a 4.75 mm size sieve so as to get uniform size of biochar. The important characteristics of biochar like grain size distribution, pH, moisture content, specific gravity and electrical conductivity were determined in the laboratory as per the standard methods, and results are presented in Table1.

3.2 Soil Sample

The soil samples used for study were collected from the agricultural fields of village Kosana, Jodhpur district, Rajasthan. The samples for various tests were prepared as

Fig. 4 Drum filled with agricultural waste

Fig. 5 Drum covered after initial burning and kept for 15 min for pyrolysis

Fig. 6 Biochar produced by pyrolysis

Table 1 Physico-chemical characteristics of Biochar

Characteristic	Value	Test standards followed [15]
pH	10.2	IS: 2720 (Part 26)—1987 (Reaffirmed 2002)
Moisture (%)	7.9	IS: 2720 (Part II)—1973 (Reaffirmed 2010)
Specific gravity	1.56	IS: 2720 (Part III2)—1980 (Reaffirmed 2002)
Electrical conductivity (mS/cm)	4.28	IS: 14,767—2000
Grain size distribution		IS: 2720 (Part 4)—1985 (Reaffirmed 2006)
2–4.75 mm (coarse)	22.4	
0.425–2 mm (medium)	46.6	
0.075–0.425 mm (fine)	31.0	

the IS: 2720 (Part 1)-1983 in the geotechnical engineering laboratory of the Department of Civil Engineering, Rajasthan Technical University, Kota. The soil samples were first of all oven-dried, pulverized and then sieved through 4.75 mm size sieve to get an idea of the primary classification. The sieve size analysis gave us the constituents of soil as 68% of sand, 16.8% of silt and 15.2% of clay. Figure 7 shows the grain size distribution of soil samples and biochar.

The Atterberg limits of the soil sample were also found out in the laboratory. It was observed that liquid limit; plastic limit; and shrinkage limit of the soil were 41%, 22% and 15%, respectively. Further, the soil sample was classified as clayey

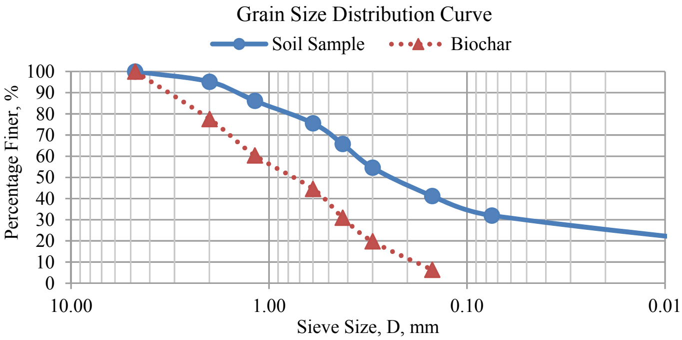

Fig. 7 Grain size distribution curve of soil sample and biochar

Table 2 Characteristics of soil sample

Characteristic	Value	Test standards followed [15]
pH	8.5	IS: 2720 (Part 26)—1987 (Reaffirmed 2002)
Specific gravity	2.62	IS: 2720 (Part III2)—1980 (Reaffirmed 2002)
Electrical conductivity (mS/cm)	0.90	IS: 14,767—2000
Grain size distribution		IS: 2720 (Part 4)—1985 (Reaffirmed 2006)
2–4.75 mm (coarse sand)	4.8	
0.425–2 mm (medium sand)	29.4	
0.075–0.425 mm (fine sand)	33.8	
0.002–0.075 mm (silt)	16.8	
<0.002 mm (clay)	15.2	
Consistency limits (%)		
Liquid limit	41	IS: 2720 (Part 5)—1985 (Reaffirmed 2006)
Plastic limit	22	IS: 2720 (Part 5)—1985 (Reaffirmed 2006)
Shrinkage limit	15	IS: 2720 (Part VI)—1972 (Reaffirmed 2001)

sand (SC) as per the Unified Soil Classification System (USCS). Table 2 represents summary of the important physical characteristics of the soil.

3.3 Biochar as Soil Amendment

To study the effect of biochar on physical properties of soil, tests were carried out in the geotechnical engineering laboratory to find out the liquid limit, plastic limit and shrinkage limit of the soil amended with different percent by weight (% w/w) of biochar like 5, 10, 15, 20 and 25%. For this purpose, the biochar was added in dry condition to the soil and the soil-biochar mix was thoroughly mixed with each other. The tests of consistency limits were performed as per the standard methods described in Table 2.

4 Results and Discussion

The effect of biochar amendment on liquid limit of the soil is shown in Fig. 8. It was found that liquid limit of the soil amended with biochar increased from 41 to 47%, 49%, 54%, 55% and remained constant at 55% on addition of biochar at 5%, 10%, 15% 20% and 25% (w/w), respectively. It can be inferred from the results that liquid limit of the soil increases with addition of biochar into it up to a certain point due to the fact that biochar has high porosity and surface area which increases the liquid limit of the soil-biochar composite.

Figure 9 shows the effect of biochar amendment on plastic limit of the soil. It was observed that plastic limit of the soil-biochar composite increased from 22 to 28% when 5% biochar (w/w) was added to the soil, and thereafter, it decreased on 10 and 15% addition of biochar. Further, it was not possible to find plastic limit of the soil-biochar composite at 20 and 25% (w/w) biochar amendment because the composite

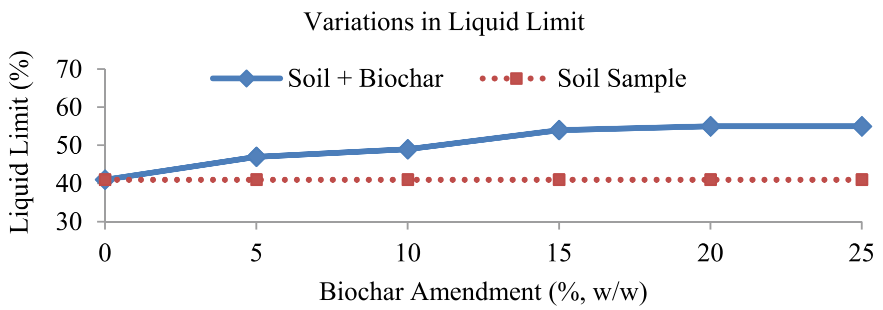

Fig. 8 Effect of biochar amendment on liquid limit of soil

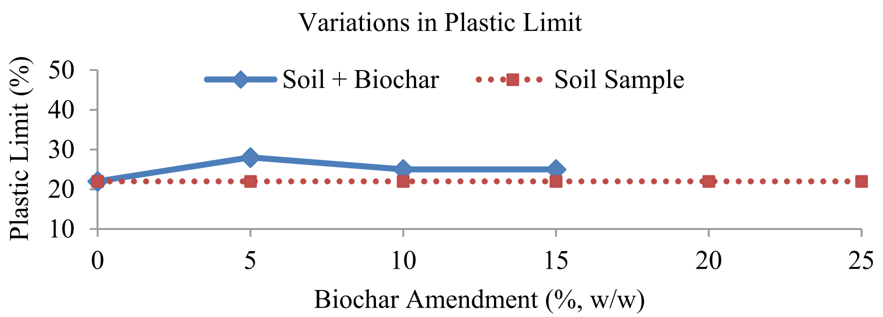

Fig. 9 Effect of biochar amendment on plastic limit of soil

did not show any plastic behavior. It crumbled at higher water contents. Hence, we can infer that the initial increase in plastic limit is because of the water-absorbing capacity of the soil-biochar composite up to a certain limit.

Figure 10 shows the variations in shrinkage limit of the soil amended with biochar at different ratios. The initial increase in shrinkage limit up to 10% addition of biochar is slightly slow, but thereafter it goes up sharply up to 25% (w/w). The increase can be seen from 15% in soil sample to 17%, 19%, 25%, 34% and 35%, respectively, in the soil-biochar composite. The increase in shrinkage limit indicates that there is higher void ratio in the biochar as compared to soil, and hence, soil amended with biochar requires more amount of water to change from solid state to semi-solid state.

Thus, we can see that values of all the consistency limits (liquid limit, plastic limit and shrinkage limit) have increased upon addition of biochar to the soil up to a certain percent by weight, and therefore, the physical properties of the soil are improved.

Similarly, Fig. 11 shows the variations in plasticity index (difference of liquid limit and plastic limit) for the soil sample and soil amended with biochar. The values after 15% addition of biochar are not shown as it was not possible to find plastic limits of the soil composite beyond 15% biochar (w/w).

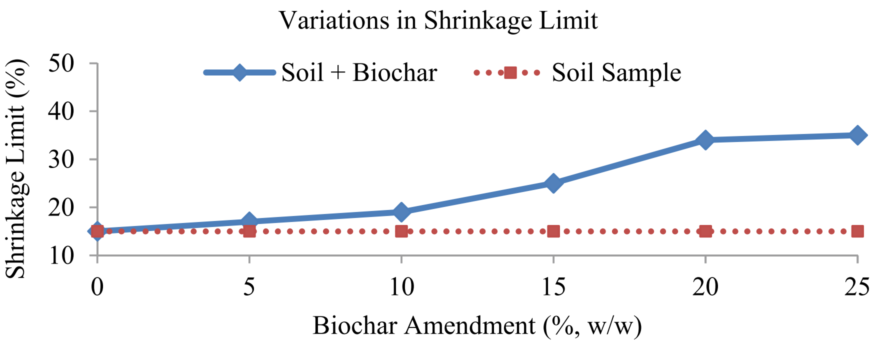

Fig. 10 Effect of biochar amendment on shrinkage limit of soil

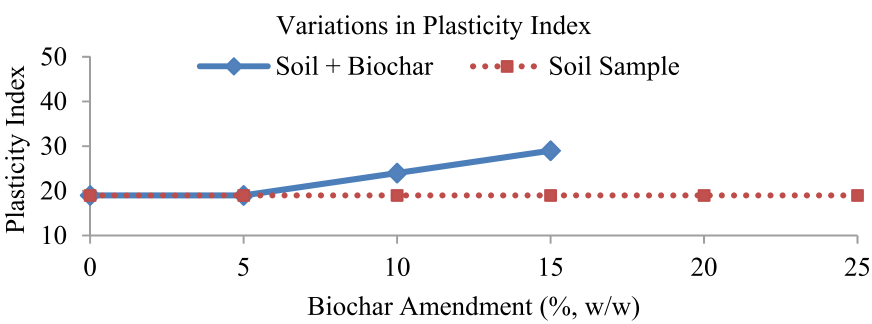

Fig. 11 Effect of biochar amendment on plasticity index of soil

5 Conclusion

The present study reveals that amendment of soil with biochar in different percent by weight has positive effect on the consistency limits of the soil. The liquid limit, plastic limit and shrinkage limit of the soil amended with biochar increase up to a certain level. Hence, the agricultural waste, which has otherwise no utility, shows a good potential of improving the soil properties. The important characteristics of high porosity and large surface area of biochar make it suitable for the soil amendment. This peculiarity of biochar can be very important in further investigation related to engineering properties like water retention capacity, hydraulic conductivity, shear strength and stability of the soil.

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