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A Novel Method of On-Site Biochar Production From Crop Residues And Further Application To Soils For Improvement In Soil Characteristics

Mahendra Pratap Choudhary[1] [0000-0003-1539-6741], H. D. Charan[2] and Biswajit Acharya[3]

[1, 3] Rajasthan Technical University, Kota, Rajasthan, India
[2] Bikaner Technical University, Bikaner, Rajasthan, India
choudhary_mp@yahoo.co.in

Abstract. It has been noticed during last four-five years that the national capital of India, New Delhi faces a peculiar problem of high air pollution and smog during *Kharif* season when crops are harvested in the nearby States of Punjab, Haryana, Uttar Pradesh and Rajasthan. It is believed that open and direct burning of agricultural crop residues by the farmers of these States is one of the responsible factors for this annual crisis. The emission of greenhouse gases during burning of crop residues is a prime factor responsible for deterioration of ambient air quality and environmental health hazard. A study has been carried out to find out an economic and optimal solution of the problem. During the process of finding a feasible solution, a novel method of on-site conversion of crop residues into a product called, biochar has been developed. The method is based on the concept of thermal conversion, wherein the crop residues are subjected to a process of pyrolysis either in the absence or little presence of oxygen. The most important feature of this method is its adoptability. The farmers can easily convert their crop residues into biochar at their own fields and the biochar so produced can be further applied to the soils to improve the soil properties which eventually lead to increased crop yield. Hence, there is a need to create awareness among the farmers about this method of biochar production and application. The novel method of producing biochar and the effect of utilizing biochar on the soil properties have been presented in this paper, which will prove useful for the Indian context where large quantities of agricultural waste are produced that create environmental air pollution when directly burnt in the fields.

Keywords: Crop Residues, Greenhouse Gases, Pyrolysis, Biochar, Soil Properties.

1 Introduction

Being an agricultural country, a huge amount of crop residue is generated per year in India. According to the Ministry of New and Renewable Energy (MNRE), Govt. of India, about 500 Million Tons (MT) of crop residue is generated per year in our country out of which about 92 MT is burned openly [1]. One of the main reasons behind it is the enhanced use agricultural machinery by the Indian framers in harvesting their crops and it has resulted into a serious problem of managing the crop residues in the form of stubble and stalks. The crop cutters and harvesters cut only the useful upper parts of the crops like wheat, mustard and paddy and remaining parts are left out in the fields and to save money and time for preparing the next crop, the farmers directly burn these residues in open fields releasing harmful greenhouse gases in atmosphere.

The annual outburst of smog during the months of October-November in the capital city of India, New Delhi, during last four-five consecutive years is known to occur due to open burning of crop residues by the farmers of nearby States of Punjab, Haryana, Madhya Pradesh, Uttar Pradesh and Rajasthan. In 2015, although, the National Green Tribunal (NGT) has imposed a complete ban on the open burning of crop residues, leaves and other materials which release toxic pollutants into the air. But, farmers are still not complying with it in its strict sense.

We can understand the severity of the problem with an example when the city of Delhi witnessed the worst category of air quality index in winter 2017. During this period, the concentration of fine particulate matter ($PM_{2.5}$) was observed at the highest level ever at 640 $\mu g/m^3$ [2] against the annual permissible limits of 40 $\mu g/m^3$ as per the national ambient air quality standards of India [3].

At present, agriculture is known to be the third largest source of greenhouse gas emission, followed by fossil fuel burning and transportation [4]. In near future, the entire developing world is likely to witness a rise in the growth of agro-processing industries which will require managing the waste generated from such industries in a well-organized and sustainable manner. The agricultural and associated agro-industries waste has the potential to provide feedstock for the production of biochar. By converting residual biomass into biochar, long-standing carbon confiscation and additional advantageous effects on soils can be ascertained [5].

The open burning of crop residues in agricultural fields is not an environment-friendly approach because it not only causes loss of biomass but also introduces harmful gases into the environment. Therefore, converting the agro-wastes into biochar rather than direct burning in open fields could be a more reliable and feasible way out to this problem of air pollution. Production and application of biochar to agricultural field soils can deal with several global and local environmental issues. Biochar application to soil also helps in carbon sequestration which ultimately converts bio-energy into a carbon-negative industry [6]. However, due to economic concerns, the use of biochar in agricultural fields has not been so encouraging [7-8].

There are studies available in literature on the factors involved in the production and use of biochar for soil amendment; but in India, not much work has been carried out yet, as it is relatively a new concept in terms of using crop residues for the production of biochar and its application. The on-site photographs taken during open burning of crop residues after harvesting are shown in Fig. 1.

Fig.1. Mustard crop residues put on fire by farmers to prepare their fields for upcoming crops near Kota, Rajasthan, India

Looking to severity and frequent occurrence of annual smog outbursts due to stubble burning throughout the country during winter months, it has been decided to find out an economic and feasible solution of this geo-environmental issue. A novel method of on-site conversion of crop residues into a product known as biochar has been discovered during the process which will not only solve the problem of timely clearance of agricultural fields after harvesting, but will also help in mitigating the environmental pollution, stabilizing the soil, increasing the fertility of the soil and hence an all-in-one solution to so many concerns.

2 Biochar

Biochar is a carbon-affluent product formed by the pyrolysis process, in which the biomass or other organic substance is heated either in the absence of or with a limited amount of oxygen at temperatures above 250°C [9]. The charcoal is also made with the same process but biochar is altogether taken as a different product than charcoal and other carbon products in that it is used as a soil amendment [10]. In recent times, biochar has drawn more attention due to its scope and role in alleviation of climate change and potential for soil amendment and sustainable cultivation [11].

Biochar can be made from biomasses having different physical and chemical properties. An extensive range of feedstock biomasses can be used for producing biochar like agricultural and organic waste, forest residues, bioenergy crops, kitchen waste and even sewage sludge also [12]. The properties of each biomass feedstock like moisture and ash content, calorific value, mass, density, particle size, fixed carbon and volatile ingredients are different and hence the produced biochars also have unique physical and chemical properties [13].

Biochar can also be produced from waste materials including those that may otherwise produce even more harmful greenhouse gases (e.g., manure or green wastes) [10]. So, it is beneficial to make use of waste materials in a useful manner and safe disposal at the same time. Production of biochar and its presence in soils has been recommended as a way of extenuating climate change by confiscating carbon and at the same time providing energy and increased crop yields [14].

Other than crop residues, 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 weeds, available locally, then it can reduce the weed mass in the fields on one hand and on the other, it can enhance the growth of plants by improving the physical, chemical and biological characteristics of soil and hence contributing to increased crop yield [15].

The biomass can be pyrolyzed in a reactor through gasification or carbonization at different temperature and time depending on the final anticipated use of the end product [16]. Biochar obtained at high temperatures (500ºC) has been found apposite for direct use as a fuel because of high contents of carbon, retention time, pH and electrical conductivity whereas biochars obtained at low temperatures (300 to 350ºC) are found appropriate for land application [17].

3 Materials and Methods

3.1 A novel method of On-site Biochar production

For Indian conditions, biochar can be produced by individual farmers on 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. A novel method of producing biochar has been developed wherein the agricultural waste is heated in empty diesel drums of capacity 220 liters, which are generally available with farmers. The arrangement of drum, feeding agricultural waste into it, igniting the residues, raw biochar produced and biochar in final finished form are shown in Fig. 2 to Fig. 4.

Fig.2. Field Arrangement showing empty diesel drums for in-situ production of biochar.

Fig.3. Drums are filled with crop residues, compacted and covered with top lid after lit on fire at bottom and left for sometime so that pyrolysis takes place.

Fig.4. The crop residue is converted into biochar in 15-20 minutes, which is further pulverized (into powder form) before addition to soil for lab experiment/field application.

The biochar so produced, was characterized by finding out its physical and chemical characteristics in the laboratory and the results are presented in Table 1 below.

Table 1. Physico-chemical Characteristics of Biochar

S. No.	Characteristics	Value
1	Colour	Black
2	pH	10.13
3	Natural Moisture Content (%, at 105°C)	18.64
4	Specific Gravity	1.61
5	Electrical Conductivity (mS/cm, at 25°C)	10.54
6	Organic Carbon (%, as OC)	1.48
7	Organic Matter (%)	2.55
8	*Grain Size Distribution (%)*	
	(i) 2 mm – 4.75 mm (Coarse)	22.8
	(ii) 0.425 mm – 2 mm (Medium)	43.4
	(iii) 0.075 mm – 0.425 mm (Fine)	33.8

3.2 Soil sample

The soil samples for the study were collected from a field at Baran road near Kota, Rajasthan from a depth of up to 1.0 m below the ground level so as to exclude any type of organic matter. The samples were collected and sealed in plastic bags and brought to the laboratory. The samples for various tests were prepared in the soil engineering laboratory of the department of Civil Engineering, Rajasthan Technical University, Kota according to the procedures laid down by the Bureau of Indian Standards in IS: 2720 (Part 1)–1983[18]. The samples were first of all oven dried, pulverized and then sieved through a 4.75 mm size sieve to get an idea of the primary classification. In sieve size analysis, the constituents of soil were found as 48% of sand, 45% of silt and 7% of clay. The Atterberg limits of the soil sample were found out. It was observed that liquid limit; plastic limit and shrinkage limit of the soil were 58.26%, 29.32% and 14.13% respectively. Further, the soil sample was classified as CH (Inorganic clay of high plasticity) as per the Unified Soil Classification System (USCS). This type of soil is generally expansive soil by nature which needs to be stabilized before construction of any pavement or load bearing structure on it.

3.3 Methods

The biochar produced at field level was used for stabilization of expansive soil. Many researchers had used lime, rice husk, fly ash and other conventional materials for the stabilization of soil but not much reference is available in literature about the application of biochar for soil stabilization. Therefore, this study was carried out to find out the applicability of biochar in soil stabilization and amendment. The test methods and standards that had been followed during experimental work were the standards as prescribed by the Bureau of Indian Standards in different parts of IS: 2720 like pH, specific gravity, moisture content, grain size distribution, consistency limits, Proctor test, unconfined compressive strength, CBR, shear strength characteristics, swelling pressure and free swell index [19-31]. Table 2 represents summary of the important physical and engineering characteristics of the soil. Fig.5 shows the grain size distribution of soil sample and biochar produced.

Table 2. Characteristics of Soil Sample

S. No.	Name of Characteristics	Value
1	Colour	Red brown
2	pH	7.86
3	Specific Gravity	2.62
4	Electrical Conductivity (mS/cm)	4.35
5	Natural Moisture Content (%)	10.23
6	Optimum Moisture Content (%)	25.35
7	Maximum Dry Density (g/cc)	1.765
8	*Grain Size Distribution (%)*	
	(i) 2 mm – 4.75 mm (Coarse Sand)	4.4
	(ii) 0.425 mm – 2 mm (Medium Sand)	20.2
	(iii) 0.075 mm – 0.425 mm (Fine Sand)	23.4
	(iv) 0.002 mm – 0.075 mm (Silt)	45.0
	(v) < 0.002 mm (Clay)	7.0
9	*Consistency Limits (%)*	
	(i) Liquid Limit	58.26
	(ii) Plastic Limit	29.32
	(iii) Plasticity Index	28.94
	(iv) Shrinkage Limit	14.13
10	Unconfined Compressive Strength (Kg/cm^2)	1.17
11	California Bearing Ratio (%)	1.55
12	Direct Shear Test	
	(i) Cohesion (C, Kg/cm^2)	0.065
	(ii) Angle of internal friction (ϕ, degree)	26.24

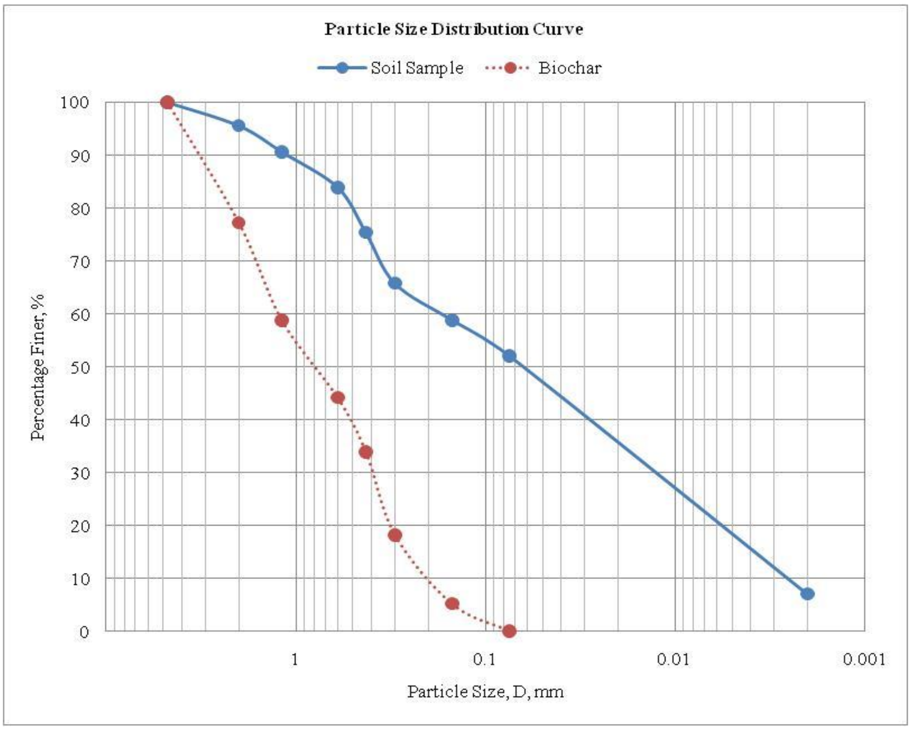

Fig.5. Grain Size Distribution Curve of Soil sample and Biochar

3.4 Biochar as soil amendment

To study the effect of biochar on physical and engineering properties of soil, various tests were carried out in the geotechnical engineering laboratory wherein the expansive soil was 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.

4 Results and Discussion

4.1 Index properties

The effect of biochar amendment on consistency limits of the soil is shown in Fig.6. It was found that liquid limit of the soil amended with biochar decreased from 58.26% to 49.32% on addition of biochar. The percentage reduction in liquid limit is approximately 4.98%, 12.22%, 13.82%, 14.98% and 15.35% respectively. This reduction is due to replacement of soil fines by biochar because it has high affinity for water. Biochar acts as a stabilizer and hence the liquid limit of the soil-biochar mix is reduced.

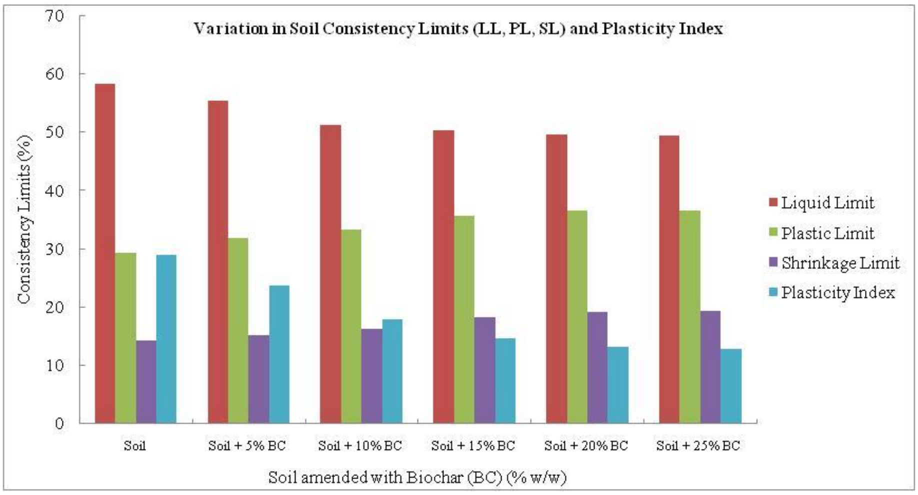

Fig.6. Effect of Biochar Amendment on Consistency Limits of Soil

The plastic limit of the soil-biochar composite increased from 29.32% to 36.56% when biochar was mixed with soil. The percentage increase in plastic limit is observed as approximately 8.29%, 13.37%, 21.59%, 24.18% and 24.69%. Here, we can infer that the increase in plastic limit is because of the water absorbing capacity of the soil-biochar composite. The increase in shrinkage limit was observed from 14.13% to 19.25% on addition of biochar and hence the percentage increase in shrinkage limit is observed as approximately 6.86%, 14.86%, 29.16%, 35.14% and 36.23%. The plasticity index of the soil amended with biochar decreased from 28.94% to 12.76% on addition of biochar. The percentage reduction in plasticity index is approximately 18.42%, 38.15%, 49.69%, 54.66% and 55.91% respectively. The decrease in liquid limit and plasticity index by adding biochar to the soil up to a certain percent by weight shows that the index properties of the soil have enhanced.

4.2 Compaction characteristics

The compaction characteristics of soil and soil-biochar mix were found out using Proctor Test according to the IS standards in which maximum dry density (MDD) and optimum moisture content (OMC) were found out at varying percentages of biochar amendment at a rate of 5%, 10%, 15%, 20% and 25%. The value of MDD of soil i.e. 1.765 g/cc decreased to 1.345 g/cc at a rate of 7.99%, 12.97%, 20.23%, 23.17% and 23.80% respectively as we added biochar content to it as shown in Fig. 7. One of the possible reasons for reduction in maximum dry density may be low specific gravity of biochar in comparison to the soil. Another reason may be the coating of soil particles by biochar resulting in larger particles with increased voids and hence less density.

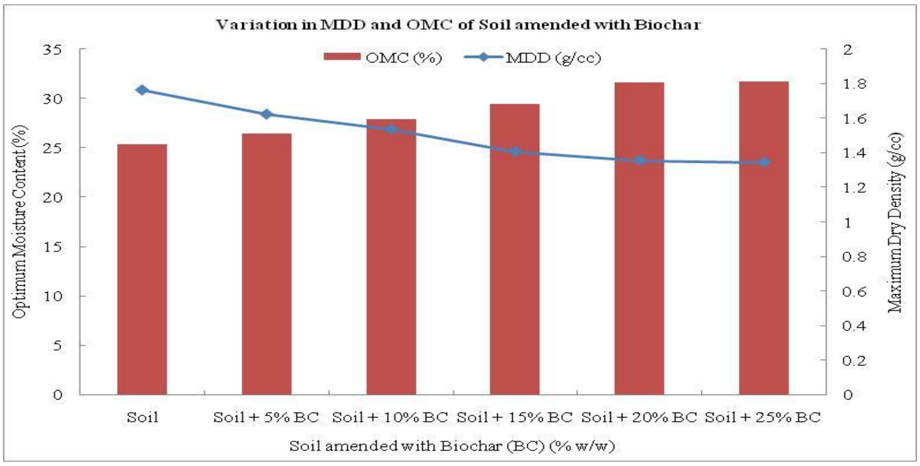

Fig.7. Variation in MDD and OMC of Soil amended with Biochar

The value of OMC i.e. 25.35% went on increasing up to 31.70% at a rate of 4.26%, 10.14%, 16.21%, 24.97% and 25.05% respectively. The increase in optimum moisture content may be attributed to the absorption of moisture by the biochar. Fig. 8 shows the variation in MDD with respect to OMC.

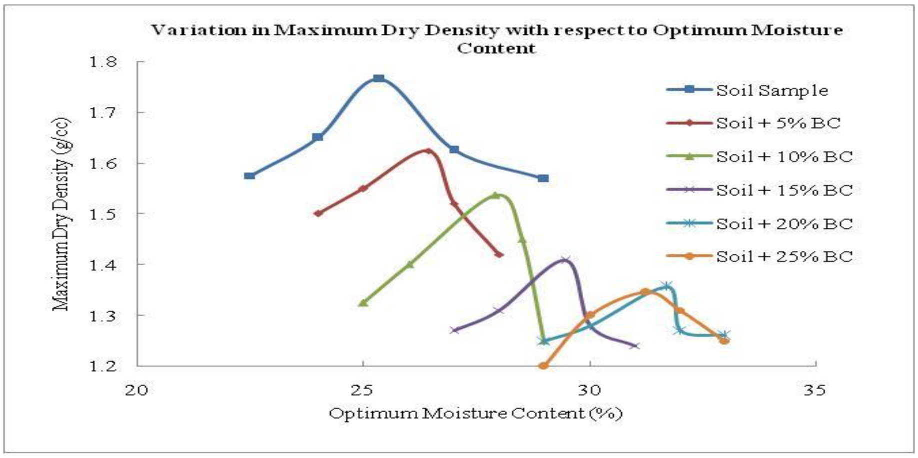

Fig.8. Variation in MDD with respect to OMC for different percentages of Biochar

4.3 Swelling pressure characteristics

We know that expansive soils have more swelling capability as there exist clay minerals which are swelling dominant. It has been observed that both swelling pressure and free swell index (FSI) of the soil go on decreasing on addition to biochar to it. The value of swelling pressure starts decreasing from 3.05 kg/cm^2 to 2.32 kg/cm^2 at a rate of 2.95%, 7.21%, 19.02%, 22.95% and 23.93% respectively on addition of biochar. The variation in swelling pressure and FSI is shown in Fig. 9.

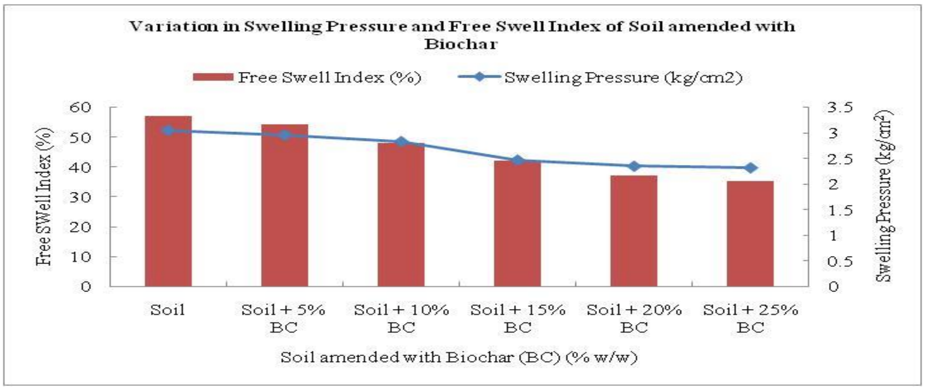

Fig.9. Variation in Swelling Pressure and Free Swell Index of Soil amended with Biochar

Similarly, the value of FSI of the soil goes on reducing from 57% to 35% at a rate of 5.26%, 15.79%, 26.32%, 35.09% and 38.60% respectively. The reduction in swelling pressure implies that as more biochar is mixed, soil becomes more stable due to decrease in the swelling potential of the compacted soil.

4.4 Unconfined compressive strength characteristics

Another important parameter of expansive soil is the unconfined compressive stress, which was found as 1.17 kg/cm^2 for the soil sample and it went on increasing on addition of biochar. The increase was observed at a rate of 7.69%, 19.66%, 32.48%, 39.32% and 41.88% respectively. Fig. 10 represents the variation in compressive stress with respect to strain for different percentages of biochar addition to soil.

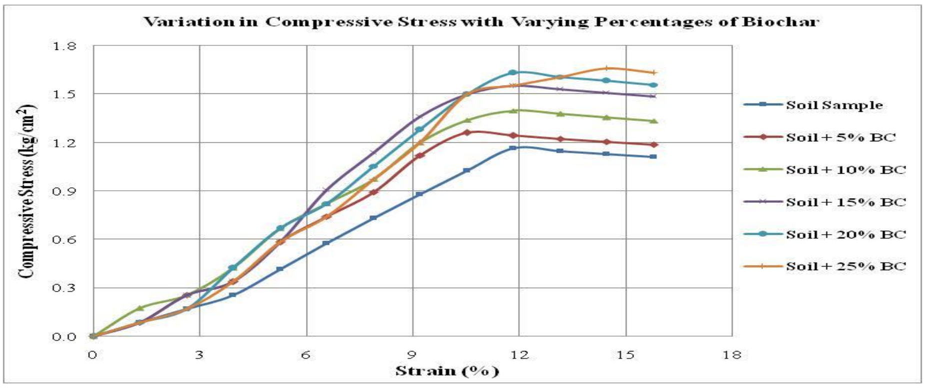

Fig.10. Variation in Compressive Stress with respect to Strain for Soil amended with Biochar

4.5 California bearing ratio characteristics

The California Bearing Ratio (CBR) test was performed to find out the variation in the penetration / bearing capacity of the soil on addition of biochar. It was observed that the value of CBR for the soil sample (1.55%) increased at a rate of 5.56%, 11.11%, 33.33%, 48.15% and 59.26% respectively on addition of biochar at 5%, 10%, 15%, 20% and 25% respectively. Fig. 11 shows the results of CBR test in which variation in load with respect to penetration is represented.

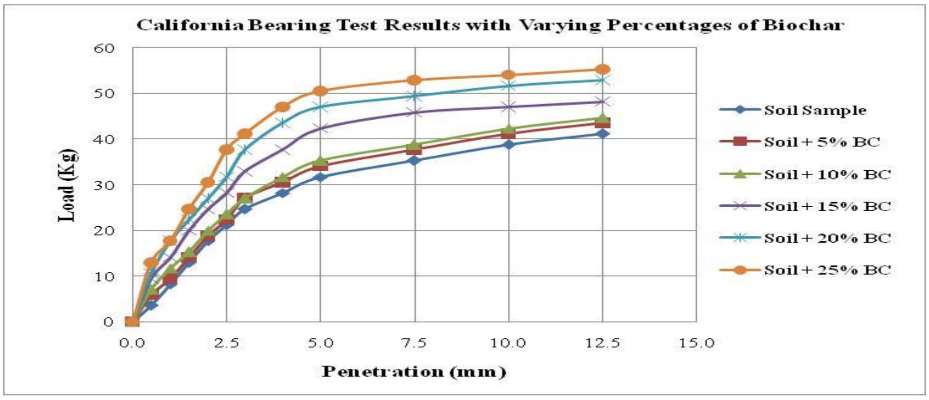

Fig.11. Variation in Load at different penetration for varying percentages of Biochar

The increase in CBR value indicates that biochar addition gives positive results and proves to be an apt stabilizer for treatment and amendment of expansive soils.

4.6 Direct shear test characteristics

The direct shear test was carried out to find out the effect on shear characteristics of the soil as a result of biochar application. Initially, the value of cohesion (C) and angle of internal frictions (ϕ) of the soil were observed as 0.065 kg/cm^2 and 26.24° respectively. Upon addition of biochar, both the values of C and ϕ increased considerably as shown in Table 3. The increase in value of C was observed up to a level of 150.77%, which is quite significant and verifies the hypothesis that biochar is a good stabilizer for expansive soils. Fig. 12 represents the variation in shear stress with regard to normal stress.

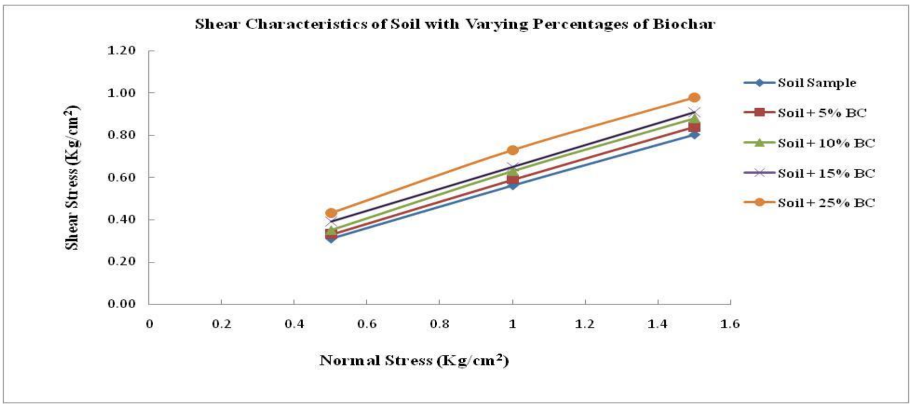

Fig.12. Variation in Shear Stress with respect to Normal Stress for Soil amended with Biochar

Table 3. Variation in Values of C and ϕ

S. No.	Soil Sample amended with Biochar	ϕ (in degrees)	Value of C (Kg/cm^2)
1	Soil	26.24	0.065
2	Soil + 5% BC	27.02	0.076
3	Soil + 10% BC	27.92	0.090
4	Soil + 15% BC	27.47	0.130
5	Soil + 20% BC	28.37	0.156
6	Soil + 25% BC	28.81	0.163

5 Conclusions

Biochar production from crop residues and agricultural wastes and its application in soils puts forward numerous environmental and economical benefits. Applying biochar in soils for amendment of soil properties has shown positive results. The major engineering characteristics of expansive soils including consistency limits, maximum dry density, optimum moisture content, swelling pressure and free swell index, unconfined compressive strength, bearing capacity and shear strength have improved by addition of biochar at the rate of 20% to 25% (w/w). Biochar application has a very promising prospective for development of sustainable agricultural systems in our country as well as the problem of air pollution in northern India, especially New Delhi through direct burning of agricultural waste in the nearby States of Haryana, Punjab, Uttar Pradesh and Rajasthan can be minimized. We can call it as a multi-benefit concept in which agricultural waste is utilized, soil amendment is achieved and air pollution is controlled. Finally, we can conclude in nutshell that in recent years, the research activities on the use of biochar in soils have increased manifold and the trend is expected to persist over the years due to the numerous potential benefits associated with the biochar application.

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