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Soil hydro-physical Environment as Influenced by Different Biochar Amendments

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Abstract

Biochar acts as a soil conditioner, improving soil physical properties, nutrient use efficiency and thereby increasing plant growth. An experiment was conducted at ICAR-National Organic Farming Research Institute during the year 2016−17 in order to study the effect of different levels of biochar obtained from different biomass on selected soil hydro-physical properties. In this study, a sandy loam soil was amended with four different types of biochar (maize, *Lantana camara*, pine needle and black gram) at four different rates (0, 5.0, 7.5 and 10.0 t ha^{-1}). The biochar were characterized for their physico-chemical properties. After biochar application selected soil hydro-physical properties were analyzed for bulk density, porosity, aggregate stability, mean weight diameter, hydraulic conductivity and water holding capacity. Maize biochar was showing best result for improving all the selected the soil physical properties compared to other type. With increasing rate of application of biochar soil physical properties also changed significantly. The results showed that bulk density decreased from 1.53 to 1.13 g cm^{-3} while porosity increased from 58.38 to 65.67. Aggregate stability and mean weight diameter increased from 4.13 and 2.51 to 8.29 and 2.83, respectively. But biochar amendment decreased the soil hydraulic conductivity from 0.41 to 0.16. Besides water holding capacity also increased from 11.37 to 19.8 g cm^{-3}. Finally soil moisture content increased significantly from 19.1 to 25.7 for all the biochar. These results strongly suggest positive improvement of soil hydro-physical properties following addition of biochar amendment in sandy loam soil.

Keywords: Biochar, hydro-physical properties, bulk density, hydraulic conductivity

1. Introduction

Biochar, an ancient soil conditioner or zero waste, is nothing but a carbon rich charcoal-like substance which is formed by heating the biomass in a limited oxygen condition, in a process known as pyrolysis (Abel et al., 2013). Biochar technology is called a geoengineering solution, as it has potential to actively reduce the atmospheric concentrations of green house gases (Das and Mukherjee, 2014). Intensive cultivation has led to a rapid decline in organic matter and nutrient levels besides affecting soil physical properties. Soil organic carbon is an important index of soil fertility because of its relationship to crop productivity. Declining SOC levels often leads to decreased crop productivity. Thus, maintaining SOC level is essential for agricultural sustainability. Biochar can enhance plant growth by improving soil physical condition i.e., water holding capacity, bulk density, porosity, infiltration (Das, 2016 and Das et al., 2015). Locally available biomass which is not economically important can be used as an important source of biomass for preparation of biochar. For a given rate of biochar application, differences in yield response are probably due to the interactive effect of many variables, and mainly to differences in biochar material, physical and chemical characteristics of the experimental soil land management and pyrolysis process (Dong et al., 2015). Some research has highlighted the ability of biochar to increase or maintain soil pH, as do dolomite or agricultural lime, as a fundamental element in the positive yield responses, especially in acid soils (Barman et al., 2015). To improve the soil physical properties and fertility there is a need to increase the soil organic carbon contents. Biochar is such an amendment which is recalcitrant to decomposition for a long period of time and maintain the soil organic carbon status. Biochar can affect soil aggregation through interactions with soil organic matter, minerals, and microorganisms; however, the surface charge characteristics and their development over time determine the long-term effect on soil aggregation (Lopez-Cano et al., 2016). It has been well proved that increased surface area, porosity, and lower bulk density in mineral soil with biochar can alter water retention, aggregation and soil erosion.

Incorporation of biochar into soil modifies soil physical properties such as soil structure, bulk density, porosity, texture, and particle size distribution (Khan et al., 2014).

This affects important soil function such as water holding capacity, aeration and plant growth. Biochar can alleviate soil compaction by decreasing bulk density, which increase porosity and accentuates favourable soil processes. Application of biochar as a soil amendment reduces tensile strength and penetration resistance (Kammann et al., 2015). In addition to improve soil mechanical properties, it also increase water infiltration rate, reduces runoff and decreases erosion. Biochar reduces saturated hydraulic conductivity in coarse textured soil and increases hydraulic conductivity in heavy textured soil by improving macro pores Haefele et al. (2011). Asai et al. (2009) reported improved saturated hydraulic conductivity of a top soil. Novak et al. (2012) reported an increase in water retention of a loamy sand; Brockhoff et al. (2010) reported an increase in water retention but a decrease in saturated hydraulic conductivity for sand based root zones; Busscher et al. (2010) reported a decrease in soil penetration resistance, but the impact on soil aggregation, infiltration, and water-holding capacity showed mixed results. Novak et al. (2012) reported enhanced moisture storage capacity of Ultisols and Aridisols. Positive effects of biochar have been reported on soil nutrient status and C sequestration, microbial community or soil biota, and greenhouse gas (GHG) emissions which are related to chemical and biological properties of soils. However, there is little published information about effects of biochar on soil hydro-physical properties. Thus, the objectives of this paper are to create some information regarding the effect of different biochar obtained from different biomass on soil hydro-physical properties.

Table 1: Textural and physico-chemical properties of the experimental soil

Physico-chemical properties	Value
pH	5.1
Texture	Sandy loam
Sand, 0.02-2 mm (%)	45.1
Silt, 0.002-0.2 mm (%)	27.3
Clay, <0.002 mm (%)	27.6
Organic carbon (%)	1.08
CEC (meq 100 g^{-1})	4.28
Bulk density (g cm^{-3})	1.53
Aggregate stability (%)	4.13
Mean weight diameter (mm)	2.51
Saturated hydraulic conductivity (cm s^{-1})	0.41
Particle density (g cm^{-3})	2.40
Total porosity (%)	54.38
Water in air dry soil (%)	1.1%
Volume expansion (%)	5.08%
Water holding capacity (g cm^{-3})	11.3
Specific gravity	2.39
Olsen P (mg kg^{-1})	5.24
SO_4 (mg kg^{-1})	17.24
Acid oxalate Al%	0.87%
Acid oxalate Fe%	0.64%

2. Materials and Methods

The experiment was conducted during the year 2016–17 at the experimental farm of ICAR-National Organic Farming Research Institute (formerly ICAR RC for NEH Region, Sikkim Centre) located in the Indian Himalayan region at Tadong (27°20'N latitude and 88°37'E longitude with 1350 m amsl), in the state of Sikkim, India. Soil samples used for this experiment (Inceptisol soil) were collected at a depth of 0–15 cm (plough layer) with no history of biochar application. Samples were collected in polythene bags, then dried in shade, ground, sieved through a 2 mm sieve and stored at room temperature (30±1 °C). Different physico-chemical properties of soil were analysed with standard method (Jackson, 1973). Organic carbon measured by using the Walkley and Black method (1965), clay, sand and silt measured by employing the Bouyoucos hygrometer (Bouyoucos and Cook, 1967). Soil pH (1:2.5 H_2O), cation exchange capacity [by 1 M NH_4OAc (pH 7) extraction], Olsen P (by 0.5 M $NaHCO_3$ extraction), sulfate [by 0.04 M $Ca(H_2PO_4)_2$ extraction], were measured according to Black (1965). Acid oxalate-extractable Fe and aluminum (Al) were determined for the initial soil samples by the standard methods of Blakemore et al. (1987). The physico-chemical properties of the soil are presented in Table 1.

Four different types of biochar were prepared from maize stalk, *Lantana camara* biomass, pine needle and black gram stover biomass using the slow pyrolysis method at 450 °C for 1.2 h. The biochar were applied at four different doses viz., 0, 5.0, 7.5 and 10.0 t ha^{-1}. The properties of the biochar used for this study are shown in Table 2. In laboratory, biochar was passed through a 2 mm sieve to correspond with USDA textural limit for soil. Different types of procedures were used to determine the bulk density, soil porosity, aggregate stability, mean weight diameter, water holding capacity, hydraulic conductivity and soil moisture content of the soil under study. Different types of biochar were mixed with the sandy loam soil with various levels viz., 0, 5.0, 7.5 and 10.0 t ha^{-1}. Each air-dried sample was packed in a standard brass core, with successive amounts of about 5 cm^3 of material added gradually with frequent stirring to avoid layering. Cylinders were tapped smoothly until they were completely full (Blake and Hartage, 1986). All the samples were packed in triplicate. Thus for all the properties under this experiment, the values were obtained from the average of triplicates. The experiment was laid out in a Completely Randomized Block Design (CRBD). For the determination of bulk density, to obtain the oven-dry mass core samples were placed in the oven at 105 °C for 24 h. The volume of the samples was calculated from the

Table 2: Chemical properties of biochar derived from different biomass

Parameters	Maize stock biochar	*Lantana camara* biochar	Pine needle biochar	Black gram stover biochar
Volatile organic content (%)	19.6	15.7	13.6	17.6
pH	9.38	9.21	9.03	8.91
Moisture content (%)	12.9	10.3	8.6	9.8
Total N (g kg^{-1})	11.3	7.2	6.8	12.8
Total P (g kg^{-1})	1.93	1.81	1.53	1.73
Total C (g kg^{-1})	715	735	724	703
Ash (%)	21.5	25.7	29.7	34.3
CEC (cmol kg^{-1})	37.6	29.7	24.2	18.3
Alkalinity	135.2	121.3	115.9	109.3
Ca (g kg^{-1})	7.52	7.51	7.39	7.12
Mg (g kg^{-1})	5.36	5.16	5.02	4.97
K (g kg^{-1})	21.8	20.1	19.8	19.1
Na (g kg^{-1})	7.3	7.2	6.9	6.7
Bulk density (g ml^{-1})	0.31	0.34	0.37	0.41
Water holding capacity	179	165	157	151
Surface area (m^2 g^{-1})	2.1	1.9	1.7	1.4
Total pore volume (ml g^{-1})	0.95	0.92	0.91	0.87

volume of the core with a Vernier caliper used to measure the height and internal diameter. Hence, the bulk density was determined by calculating the ratio of the oven-dry mass to volume of the sample (g cm^{-3}). Soil textural analysis was determined using the Bouyoucos hydrometer method (Gee and Bauder, 1979). Total porosity was calculated from bulk density using the formualar: $Tp=100(1–B_d/P_d)$; where B_d=bulk density, P_d=particle density (Obi, 2000). Hydraulic conductivity was determined using a 30.2 cm length and 4.5 cm diameter infiltrometer (Zhang, 1997). This method involves measuring cumulative infiltration against time and after then hydraulic conductivity measured through van Genuchten parameters for a given soil type. Mean weight diameter was determined by calculation as described by Kemper and Rosenau (1986). Aggregate stability was determined using the wet sieving method described by Kemper and Rosenau (1986). Moisture content was determined by calculation as outlined by Obi (2000). Water holding capacity was determined as per the procedure of Das and Mukherjee (2012). All the data obtained was statistically analysed using the F-following Gomez and Gomez. LSD values at p=0.05 were used to determine the significance of difference between treatment means.

3. Results and Discussion

AEffects of biochar on soil hydro-physical properties depend on several factors viz. biomass type, pyrolytic condition, environmental condition as well as application rate. Four different biochar from maize stalk, *Lantana camara*, pine needle and black gram stover has been prepared at 450 °C and characterized for different chemical properties (Table 2). Biochar was applied at four different rate viz. 0, 5.0, 7.5 and 10.0 t ha^{-1}. Effect of different biochar on soil porosity and bulk density on amended soil has been shown in Table 3. The results revealed that soil porosity increased with application of all type of biochar with increase in application rate. The initial porosity of the sandy loam soil was 54.38% in control (without biochar) and it increased to 65.67% with application of maize biochar, 64.42% with *Lantana camara* biochar, 63.42% with pine needle biochar and 62.35% with black gram stover biochar @ 10 t ha^{-1}. Similar results were found by Ouyang and Zhang (2013) in coarse sandy soil. Similarly the initial bulk density of the soil was 1.53 g cm^{-3} in control (without biochar) which decreased to 1.13, 1.19, 1.24 and 1.29 g cm^{-3}

Table 3: Effect of biochar on soil porosity, bulk density, aggregate stability and MWD on amended soil

Type of biochar	Application rate	Soil porosity (%)	Bulk density (g cm^{-3})	Aggregate stability %	Mean weight diameter (mm)
Maize stock biochar	0 t ha^{-1}	54.38	1.53	4.13	2.51
	5.0 t ha^{-1}	59.27	1.34	6.39	2.67
	7.5 t ha^{-1}	62.39	1.21	7.89	2.73
	10.0 t ha^{-1}	65.67	1.13	8.29	2.83
Lantana camara biochar	0 t ha^{-1}	54.38	1.53	4.13	2.51
	5.0 t ha^{-1}	58.39	1.39	6.03	2.64
	7.5 t ha^{-1}	57.51	1.28	7.69	2.71
	10.0 t ha^{-1}	64.42	1.19	8.03	2.76
Black gram stover biochar	0 t ha^{-1}	54.38	1.53	4.13	2.51
	5.0 t ha^{-1}	57.69	1.41	5.86	2.66
	7.5 t ha^{-1}	60.27	1.31	6.97	2.69
	10.0 t ha^{-1}	63.43	1.24	7.64	2.73
Pine needle biochar	0 t ha^{-1}	54.38	1.53	4.13	2.51
	5.0 t ha^{-1}	56.49	1.43	5.71	2.59
	7.5 t ha^{-1}	59.37	1.35	6.62	2.62
	10.0 t ha^{-1}	62.35	1.29	7.07	2.66
SEm±		1.41	0.01	0.31	0.06
LSD (p=0.05)		4.83	0.04	0.74	0.17

with maize, *Lantana camara*, pine needle and black gram biochar, respectively, @ 10 t ha^{-1} (Table 3). These results were similar to the experiment conducted by Khan et al., 2016. Haefele et al. (2011) also reported a decrease in topsoil bulk density for an irrigated lowland site and rainfed upland, but no effect on a rainfed lowland site. On the other hand initial soil aggregate stability was 4.13% in control (without biochar). This gradually increased with biochar application in the order 8.29, 8.03, 7.64 and 7.07%, respectively, for maize, *Lantana camara*, pine needle and black gram @ 10 t ha^{-1}. Mean weight diameter also increased from 2.51 mm (initial) to 2.83, 2.76, 2.73 and 2.66 mm, respectively, for maize, *Lantana camara*, pine needle and black gram @ 10 t ha^{-1} (Table 3). Such findings have been reported by Lehmann et al., 2011 and Lu et al., 2014. All the above mentioned physical parameter had significantly enhanced by application of biochar and also type of biochar has significant impact on the soil physical property. But the best one was maize biochar. Effect of biochar on water holding capacity, soil moisture content and hydraulic conductivity has been shown in Table 4. Results revealed that all the type of biochar increased water holding capacity as well as soil moisture content. The data indicated that water holding capacity increased with application of biochar from initial 11.3 g cm^{-3} (without biochar) to 19.8, 18.7, 17.1 and 17.8 g cm^{-3} for maize, *Lantana camara*, pine needle and black gram, respectively, @ 10 t ha^{-1}. Similarly soil moisture content also increased from initial 19.1% (without biochar) to final 25.7, 24.8, 24.5 and 24.1% for maize, *Lantana camara*, pine needle and black gram, respectively @ 10 t ha^{-1} (Table). But hydraulic conductivity decreased from initial value 0.41 cm s^{-1} (without biochar) to final value 0.16, 0.18, 0.19 and 0.21 cm s^{-1}, respectively, for maize, *Lantana camara*, pine needle and black gram @ 10 t ha^{-1} (Table 4). Interestingly, decrease in hydraulic conductivity was more in black gram biochar compared to maize and other biochar. Very similar result was obtained by Sanchez-Garcia et al., 2015; Wiedner et al., 2015.

Table 4: Effect of biochar on water holding capacity, soil moisture content and hydraulic conductivity

Type of biochar	Application rate	Water holding capacity (g cm^{-3})	Soil moisture content (%)	Hydraulic conductivity (cm s^{-1})
Maize stock biochar	0 t ha^{-1}	11.3	19.1	0.41
	5.0 t ha^{-1}	15.6	23.4	0.31
	7.5 t ha^{-1}	17.3	24.3	0.22
	10.0 t ha^{-1}	19.8	25.7	0.16
Black gram stover biochar	0 t ha^{-}	11.3	19.1	0.41
	5.0 t ha^{-1}	14.3	22.8	0.35
	7.5 t ha^{-1}	16.4	23.6	0.27
	10.0 t ha^{-1}	18.7	24.8	0.18
Pine needle biochar	0 t ha^{-1}	11.3	19.1	0.41
	5.0 t ha^{-1}	14.8	22.1	0.36
	7.5 t ha^{-1}	16.6	23.5	2.29
	10.0 t ha^{-1}	18.1	24.5	0.19
Lantana camara biochar	0 t ha^{-1}	11.3	19.1	0.41
	5.0 t ha^{-1}	13.1	21.7	0.34
	7.5 t ha^{-1}	15.4	23.7	0.26
	10.0 t ha^{-1}	17.8	24.1	0.21
SEm±		0.31	0.22	0.02
LSD (p=0.05)		0.88	0.64	0.05

Bulk density decreased with the rate of biochar amendment. Bulk density is a measure of the relative mass of a solid relative to the bulk volume the solid occupies, including the void spaces. Thus greater is the portion occupied by the pores, the lower is the bulk density of a solid. Lower bulk density indicates an increase in pore space which enhances the potential for soil aeration and increase water holding capacity. However, as reported by Githinji et al. (2011), besides bulk density other physical indicator also important for management of soil quality. In this research experiment porosity increased with increased rate of biochar application which has already documented by Tang et al., 2013. The decrease in hydraulic conductivity was significant as a function of biochar amendment; this was likely due to the hydrophobicity of the organic matter present in biochar amendment Jein and Wang (2013). He indicated a significant decrease in bulk density, increase in porosity and decrease in saturated hydraulic conductivity with biochar application. The increase in total porosity and decrease in bulk density with biochar application might be caused by physical dilution effects (Busscher et al., 2011). They indicated that increasing TOC by biochar amendments addition in soils decrease bulk density significantly. The decrease in bulk density appears to have been the result of alteration of soil aggregate sizes (Vandecasteele et al., 2016). Asai et al. (2009) indicated that biochar incorporation into soil changed the pore-size distribution. This leads to increase in water permeability. The increase in mean weight diameter could be attributed to an increase in oxidized functional groups which generally produced after mineralization of biochar (Herath et al., 2013). These facilitated flocculation of both the soil particles and the biochar (Jien and Wang, 2013). Li et al. (2012) found that soil aggregate sizes and stability could be significantly increased for the sandy loam soil through the addition of biochar to the soil. In sandy soil, it also increases the water holding capacity (Oleszczuk, 2014). The unique property of biochar which makes it as an attractive soil amendment is its highly porous structure. This is responsible for increased water holding capacity and nutrient retention capacity (Prost et al., 2013). The pores in biochar provide suitable habitat for soil microbes by protecting them from predation and drying and also provide carbon, energy and mineral nutrient sources (Mukherjee et al., 2016).

4. Conclusion

Biochar amendment had a positive impact on the physical properties of soil. All the types of biochar decreased the bulk density of the soil and increased total soil porosity which would leads to enhance plant growth due to sufficient moisture and oxygen in root zone. Moreover, biochar increase aggregate stability and mean weight diameter with decreasing hydraulic conductivity of the soil. Thus different biochar have different impact on soil physical properties. However, long-term researches are needed to facilitate the understanding of effects of biochar on soil hydro-physical properties.

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