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Effect of Biochar on Improving Soil Properties of Ultisols (Typic Plinthustults)

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ABSTRACT

The present investigation was carried out to explore the beneficial effects of biochar on the soil physical and physico-chemical properties and SOC levels in the Typic plinthustults soil of Kerala. Two field experiments were carried out sequentially, wherein Chinese potato was raised to study the direct effect and cowpea was the test crop to study the residual effect of biochar on soil properties. Three levels of biochar (5, 7.5 and 10 t ha^{-1}), FYM 10 t ha^{-1}, soil test based POP with and without biochar and absolute control were the treatments. While the soil properties such as pH, EC and organic carbon was estimated after each crop, all other properties were measured only after two crops. Results showed that the soil bulk density was significantly reduced by application of biochar 10 t ha^{-1} and soil test based POP + biochar (1.23 Mg m^{-3}). Application of biochar 10 t ha^{-1} either alone or in combination with POP showed a superior effect on porosity, WHC, organic carbon and SOC storage. With respect to pH, significant improvement was noticed with application of 10 t biochar ha^{-1}. Application of biochar at higher dose (7.5 and 10 t ha^{-1}) and soil test based POP +biochar 10 t ha^{-1} were comparable and superior in terms of CEC and fractions of organic matter. Improvement in soil properties synchronized well with the increase in biochar application rate. Thus, it is clear that application of biochar could improve the soil quality and sequestration of C in soil.

Keywords Biochar, Laterite soils, Soil physico-chemical properties, Organic amendments, Soil quality.

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INTRODUCTION

The greatest challenge of our country in this 21st century is to produce food, fodder, fiber and fuel enough for the ever increasing population from a limited land resource. The mission becomes more complicated while dealing with less productive soils viz. sandy, calcareous, alkaline and acidic. Laterite and lateritic soil are formed by intensive and prolonged weathering of the underlying parent rock.Classified under the order Ultisols, these acidic soils cover nearly 65% of the total area occupying midlands and mid upland regions of Kerala. The soils are generally acidic (with Fe, Al and Mn in toxic levels), low in CEC, low to moderate in BSP, dominant in kaolinite clay, rich in sesquioxides, poor in inherent fertility, high in P fixation. The compact B horizon that inhibits root penetration, reduced soil volume, low level of organic matter, decreased moisture retention are the major constraints to crop production which can be overcome through the practice of green manuring, legume based crop rotation, regular application of manures and fertilizers and liming materials. As far as laterite soils are concerned, the continuous application of organic manures and amendments is highly essential more because of soil compaction and high rate of mineralization associated with tropical situation. It is in this context that biochar which is highly resistant to decomposition serves as a viable proposition as an amendment, in addition to sequestering carbon and managing soil health.

Biochar is defined as a carbon rich product derived from the slow pyrolysis (heating in the absence of oxygen) of organic material at relatively low temperatures (<700^{o}C) (Lehmann 2007). It holds the ability to store carbon for longer periods of time as it is more stable in soil (100–1000 years) chemically and biologically than the source material. Production of biochar and its storage in soils has been suggested as one of the possible means of reducing the atmospheric CO_2 concentration. The climate mitigation potential of biochar stems primarily from its highly recalcitrant nature which slows the rate at which photosynthetically fixed carbon is returned to the atmosphere. Considering the possible strategies to remove CO_2 from the atmosphere, biochar is notable, if not unique, in this regard for sequestering carbon in soil thus mitigating climate change effects and global warming.

Amelioration of degraded soil and reduction of soil acidity brought about by biochar addition are made possible by the chemically reactive groups (such as carboxyl, hydroxyls and ketones) which help to adsorb toxic substances like Al and Mn from acid soils (Abewa et al. 2014, Lin et al. 2018). The increased surface area offers higher potential to hold water and nutrients leading to increased crop growth and production. Improvement in soil pH, increase in CEC, increased biological nitrogen fixation, reduced leaching loss of nutrients, creation of favorable environment for microbial activity and decreased degradation of the soil stand out as the positive effects biochar application.

Recently, soil quality has gained attention as a result of environmental issues related to soil degradation and production sustainability under different farming systems. The properties such as bulk density, porosity, WHC, pH and organic carbon content of soil are considered as good indicators of soil quality and productivity because of their favorable effect son the physical, chemical and biological properties of soil. Accounting the properties of laterite soils and the positive traits of biochar, the present investigation was carried out to study the effect of biochar on soil physical, physico-chemical properties and on SOC storage.

MATERIALS AND METHODS

The field experiments were carried out at the Agricultural Research Station, Mannuthy, Kerala during 2017-2018. The farm is located in the Agro-Climatic Zone – II (Midland laterites), Agro-ecological Unit – 10 (North Central laterites) of Kerala at 10^{o}32´ N latitude and 76^{o}10´ E longitude, at an altitude of 22.5 m above MSL. The soil of the experimental site belongs to Velappaya series, Fine loamy kaolinitic isohyperthermic soil, taxonomically Typic plinthustults.

The experimental soil was found to be sandy clay loam in texture and the bulk density and pore space were 1.32 Mg m^{-3} and 47.64%, respectively. With respect to the pH and EC, the soil was strongly acidic and non-saline. The organic carbon content was 1.55% and the CEC 3.72 cmol (+) kg^{-1}, which showed the dominance of kaolinite. With respect to the available nutrient status, it was found to be low in $KMnO_4$-N and high in Bray-P and NH_4OAC-K.

Biochar used in the study had an alkaline pH (10.01), high EC (3.42 dS m^{-1}), C (64.14%), CEC

(15.78 cmol (+) kg^{-1}) and C : N ratio (113 : 1). Total N,P, K, Ca, Mg and S contents were 0.567, 0.982, 4.175, 1.19, 0.456 and 0.244% respectively. Content of micronutrients viz. Fe, Mn, Zn, Cu and B were 1535, 83.95, 53.93, 35.5 and 55.0 mg kg^{-1}, respectively. Regarding physical properties, biochar had low bulk density (0.128 Mg m^{-3}), high porosity (84.63%) and WHC (307.3%).

The experiment was laid out in RBD with 3 replications. The treatments are as follows. T_1 : Control, T_2 : FYM 10 t ha^{-1}, T_3 : Biochar 5 t ha^{-1}, T_4 : Biochar 7.5 t ha^{-1}, T_5 : Biochar 10 t ha^{-1}, T_6 : Soil test based POP + biochar 10 t ha^{-1} and T_7 : Soil test based POP. The Package of Practices of Kerala Agricultural University recommends a fertilizer dose of 60 : 60 : 100 kg NPK + 10 t FYM per hectare for Chinese potato. In order to apply fertilizers based on soil test values, the initial soil samples were analyzed for its available NPK content and quantity of fertilizers to be applied was calculated based on modified RDF. Full dose of P was applied basally, whereas N and K were applied in two splits as basal (50%) and 45 DAS (50%), Urea (46% N), rock phosphate (20% P_2O_5) and MOP (60% K_2O), were used as the fertilizer source. Raised beds of 2.1 × 0.6 m size were taken manually at 45 cm apart. The fertilizers, FYM and biochar were applied as per treatments to the respective beds and surface mixed before planting.

Two field experiments were carried out sequentially, wherein Chinese potato was raised to study the direct effect of biochar and for studying the residual effect of biochar applied to the first crop, cowpea was the test crop. For raising second crop, care was taken not to disturb the soil much, maintaining the same layout. No additional manuring and fertilizer application was done to second crop in any of the plots. Soil samples collected after the harvest of crop was subjected to various analysis following the standard procedures (Table 1). The soil properties viz. pH, EC, organic carbon were estimated after each crop, whereas bulk density, porosity, WHC, CEC, SOC stock, humic acid and fulvic acid were estimated after the harvest of two crops. The parameters obtained were subjected to statistical scrutiny as outlined by Panse and Sukhatme (1978).

Table 1. Details of analytical methods employed for soil analysis. SOC stock (Mg ha^{-1}) = Bulk density (Mg m^{-3}) × OC (%) × depth (m) × 100.

Properties	Methodology	Reference
Bulk density Porosity	Cylinder method	Piper 1966
WHC	Keen-Raczkowski box method	Piper 1966
pH EC	1:2.5 soil-water suspension Potentiometry Conductometry	Jackson 1973
Organic carbon	Chromic acid wet digestion method	Walkley and Black 1934
CEC	Summation method	Hendershot and Duquette 1986

RESULTS AND DISCUSSION

Bulk density

Soil bulk density is a parameter which is dependent on clay content, organic matter and soil structure. Hence any practice that influences the soil structure and organic matter status of soil would naturally influence the bulk density. Biochar with high carbon content and low bulk density was found to significantly influence the bulk density of post-harvest soil of the present experiment (Table 2). The initial bulk

Table 2. Effect of biochar application on soil bulk density, porosity, WHC, CEC, and SOC stock.

Treatments	Bulk density (Mg m^{-3})	Porosity (%)	WHC (%)	CEC (cmol (+) kg^{-1})	SOC stock (Mg ha^{-1})
Control	1.33	46.74	30.27	4.12	62.60
FYM 10 t ha^{-1}	1.29	48.82	32.18	4.44	64.06
Biochar 5 t ha^{-1}	1.28	49.49	31.92	4.55	67.81
Biochar 7.5 t ha^{-1}	1.26	50.70	32.82	4.78	69.02
Biochar 10 t ha^{-1}	1.23	52.03	33.31	4.90	71.60
Soil test based POP + biochar 10 t ha^{-1}	1.23	51.92	34.23	4.95	70.78
Soil test based POP	1.28	48.57	32.56	4.53	64.92
CD (0.05)	0.022	0.82	1.25	0.26	1.29

density of the experimental soil was 1.32 Mg m^{-3}, which decreased with the application of treatments. Among the different treatments tried, the bulk density was significantly minimum for the treatments biochar 10 t ha^{-1} and soil test based POP + biochar 10 t ha^{-1}. The different levels of biochar tried also decreased the bulk density, though the difference between 5 and 7.5 t ha^{-1} biochar was only comparable. Application of FYM 10 t ha^{-1} alone or combination with NPK had a comparable effect. Control plots recorded significantly higher bulk density as against treatments. The decrease in bulk density due to biochar addition can be primarily attributed to the low bulk density of the material itself (0.128 Mg m^{-3}) and to increase in soil organic matter and pore space consequent to its application. Significant decrease in bulk density of the biochar applied fields was also reported by Elangovan (2014), Dainy (2015), Rajalekshmi (2018).

Porosity

With respect to the porosity, the maximum value was recorded in the treatments that contained higher dose of biochar i.e. biochar 10 t ha^{-1} (52.03%) and soil test based POP + biochar 10 t ha^{-1} (51.92) (Table 2). Levels of biochar had significant effect on porosity as reflected from initial porosity value of 46.78% getting increased to 49.49, 50.69 and 52.03% in the treatments biochar 5, 7.5 and 10 t ha^{-1}, respectively. As could be expected, the lowest value was associated with control plots. The increase in soil porosity can be primarily ascribed to the highly porous nature of biochar itself (84.63%). Increase in total porosity and soil water retention as a result of macro aggregate formation in rice soils due to biochar application was also reported by Sharma and Uehara (1986).

Water holding capacity

The data furnished in Table 2 shows the positive effect of different treatments on the WHC of soil. The highest WHC of 34.23% was recorded in the soils that received soil test based POP + biochar, followed by biochar 10 t ha^{-1} (33.31%) which were at par. As could be anticipated, with an increase in the biochar levels, WHC also increased. Significantly lowest WHC was recorded in absolute control (30.27%). Changes in the WHC of the soil was primarily responsible for the water holding capacity of the added biochar (307.7%). The increase in particle surface area and the porous structure of biochar were stated responsible for the increase in the WHC of soil consequent to biochar application (Lehmann et al. 2003). The formation of humic substance in soil following biochar application is another reason for the increased WHC as reported by Piccolo et al. (1996).

Soil reaction

Statistical scrutiny of the data revealed that there was significant difference among the treatments with respect to soil pH (Table 3). The initial pH of the experimental soil was 5.24. Maximum pH of 5.95 was observed in the treatment biochar 10 t ha^{-1} and was superior to all other treatments. In the succeeding crop also the higher value was associated with the same treatment. However, it was at par with the application of soil test based POP + biochar (5.98) and biochar

Table 3. Effect of biochar application on physico-chemical and chemical properties of post-harvest soil.

Treatments	pH			EC (dS m^{-1})			Organic carbon (%)		
	1st crop	2nd crop	Mean (T)	1st crop	2nd crop	Mean (T)	1st crop	2nd crop	Mean (T)
Control	5.21	5.43	5.32	0.054	0.061	0.058	1.581	1.573	1.577
FYM 10 t ha^{-1}	5.36	5.86	5.61	0.058	0.070	0.064	1.696	1.660	1.678
Biochar 5 t ha^{-1}	5.49	5.89	5.69	0.048	0.066	0.057	1.790	1.771	1.780
Biochar 7.5 t ha^{-1}	5.65	5.96	5.80	0.050	0.058	0.054	1.828	1.824	1.826
Biochar 10 t ha^{-1}	5.86	6.04	5.95	0.050	0.058	0.054	1.933	1.942	1.938
Soil test based POP + biochar 10 t ha^{-1}	5.71	5.98	5.84	0.084	0.066	0.075	1.925	1.913	1.919
Soil test based POP	5.27	5.67	5.47	0.068	0.070	0.069	1.695	1.686	1.691
Mean (S)	5.51	5.83		0.059	0.064		1.778	1.767	
	S	T	T × S	S	T	T × S	S	T	T × S
CD (0.05)	0.047	0.088	0.124	0.002	0.004	0.006	0.014	0.026	0.037

7.5 t ha^{-1} (5.96). Irrespective of the treatments, soil pH increased significantly in the succeeding crop. Increase in pH with an increase in levels of biochar was also observed. In both the experiments, the lowest pH was recorded in control.

The increased concentration of alkaline metal oxides (Ca, Mg and K^+) contained in the biochar and also the reduced concentration of soluble soil Al^{3+}, the high liming potential of biochar that raises the pH of the highly weathered soil (Jien and Wang 2013, Dainy 2015) and also the typically alkaline nature of biochar itself (pH 10.01) (Shenbagavalli and Mahimairaja 2012, Elangovan 2014, Akshatha 2015, Dainy 2015). These are the probable reasons pointed out behind the increase in pH following biochar application. Several researchers from their works on biochar reported that, when biochar is applied, the CEC of soil gets increased which would give a chance for Al and Fe to get bound with the soil exchange sites, leading to a reduction in exchangeable Al and soluble Fe in soils, which fully agrees with the findings of the present study also . The association of functional groups such as -COO - (-COOH) and –O-(-OH) contained in the biochar with H^+ also contributed considerably to the alkalinity as suggested by Yuan et al. (2011).

Electrical conductivity

The EC values of post-harvest soil as influenced by different treatments is presented in Table 3. The highest EC values was registered in the treatment soil test based POP + biochar (0.084 dS m^{-1}), followed by soil test based POP application (0.068 dS m^{-1}) and the difference was significant. The effect of all other treatment were at par. In the succeeding crop, the effect of different treatments on EC was only comparable. The increase in soluble salt content of soil might be due to the higher proportion of soluble salts added through biochar leading to an increase in electrolytes content resulting in an increase in soil EC. Biochar used in the present study recorded an EC of 3.42 dS m^{-1}. The finding of this investigation synchronizes with that of Nigussie et al. (2012), Shenbagavalli and Mahimairaja (2012), Elangovan (2014), Akshatha (2015), Dainy (2015). Another possible reason for the increased EC might be due to the release of cations and anions which are loosely bound with biochar into the soil solution making it available for plant growth (Chan et al. 2008).

Cation exchange capacity

The results of the cation exchange capacity of soil after the harvest of two successive crops is shown in Table 2. The initial CEC of the soil was 3.72 cmol (+) kg^{-1} and an increase in the value was observed with the application of biochar. The highest CEC was recorded in the treatments soil test based POP + biochar (4.95 cmol (+) kg^{-1}), biochar 10 t ha^{-1} (4.90 cmol (+) kg^{-1}) and biochar 7.5 t ha^{-1} (4.78 cmol (+) kg^{-1}) which were at par with each other. With an increase in the biochar application rate, CEC increased . As could be expected, significantly lowest CEC was recorded in absolute control (4.119 cmol (+) kg^{-1}).

The increase in CEC following biochar application can primarily be attributed to its high CEC (15.78 cmol (+) kg^{-1}), high specific surface area, high surface negative charge and charge density, as opined by several researchers from their works on biochar. In addition, the slow oxidation of biochar resulted in an increase in number of carboxylic and phenolic functional groups which finally increased the CEC of amended soil. Another reason for increase in the soil CEC is the increase in the pH dependant charges that resulted from the increase in pH of the respective treatments. This is in accordance with the findings of Jien and Wang (2013) who observed an improvement in soil CEC from 7.41 to 10.8 cmol (+) kg^{-1} where pH increased from 3.90 to 5.1 with the application of 2 and 5% biochar, to an acidic Ultisol. Similar observation was also noticed by van Zwieten et al. (2010) in a Ferralsol soil conducted under greenhouse condition. Increase in CEC with the application of biochar was also reported by Chan et al. (2008), Shenbagavalli and Mahimairaja (2012), Elangovan (2014), Dainy (2015), Rajalekshmi (2018).

Organic carbon

Application of different levels of biochar significantly influenced the organic carbon content of post-harvest soil (Table 3). The initial organic carbon content of the experimental soil was 1.55% and an increase in the value owing to the application of treatments was observed. In both the main and succeeding crop, application of biochar 10 t ha^{-1} either alone or in combination with soil test based POP showed a superior effect by registering significantly higher organic carbon values. As could be expected, significantly lowest organic carbon was recorded in the absolute control, in both experiments (1.581 and 1.573%, respectively). With an increase in levels of biochar, significant increase in organic carbon was noticed and the trend was similar in the case of residual effect also.

The positive effect of biochar on SOC is primarily due to the high amount of C contained in biochar (64.14%). In addition , the existence of recalcitrant organic carbon in biochar also add on to the SOC level (Nigussie et al. 2012). Another highlight on soil organic carbon data of the present experiment is that there was no significant reduction even after the second crop in the biochar applied treatments. This might be due to the highly persistent nature of biochar in soil than any other form of organic manure which makes it classic for sequestering carbon. Ample research findings support the data on organic carbon as acquired in the present investigation. Application of FYM at the rate similar to that of biochar failed to enhance the organic carbon content of soil as evidenced from the second crop data, which may be due to its higher rate of decomposition prevalent in tropical soils.

Soil organic carbon stock

The SOC stock in post-harvest soil was also influenced by biochar application and it showed similar trend as that of the organic carbon content (Table 2). Application of biochar 10 t ha^{-1} either alone or in combination with soil test based POP resulted in maximum C storage (71.60 and 70.78 Mg ha^{-1}). Effect of biochar 5 and 7.5 t ha^{-1} on C stock was comparable. Similarly, application of FYM either alone or in combination with NPK showed comparable effect. Significantly lower C storage was observed in control plots.

The higher concentration of SOC in biochar applied soil ranging from 67.81 to 71.60 Mg ha^{-1} might be due to the potential of biochar to increase the

Table 4. Effect of biochar application on fulvic acid and humic acid content.

Treatments	Fulvic acid	Humic acid
	%	
Control	6.10	2.36
FYM 10 t ha^{-1}	6.40	2.78
Biochar 5 t ha^{-1}	6.53	3.60
Biochar 7.5 t ha^{-1}	6.53	4.57
Biochar 10 t ha^{-1}	6.40	4.63
Soil test based POP + biochar 10 t ha^{-1}	6.40	5.13
Soil test based POP	5.77	3.40
CD (0.05)	0.29	0.72

recalcitrant pool of soil carbon which would persist in the soil environment much longer than carbon in the form of residues or biogenic soil organic matter. Similar views on significant increase in SOC content and its probable addition to the decadal soil carbon pool has been also expressed by Shenbagavalli and Mahimairaja (2012), Rajalekshmi (2018).

Fractions of organic matter

Effect of treatments viz. biochar 7.5 t ha^{-1} , biochar 5 t ha^{-1}, biochar 10 t ha^{-1} , soil test based POP + biochar and FYM 10 t ha^{-1} on fulvic acid was comparable. Significantly lowest fulvic acid was observed in soil test based POP (5.77%) (Table 4). Regarding the humic acid content it was higher in the soils applied with soil test based POP + biochar (5.133%), biochar 10 t ha^{-1} (4.633%) and biochar 7.5 t ha^{-1} (4.567%) which were all comparable. With an increase in the rate of biochar application, humic acid content increased. Lowest amount of humic acid was registered in control (2.367%), which was at par with FYM 10 t ha^{-1} (2.767%). The results reflected that large amount of C got sequestered in the soil due to application of biochar. Similar was the findings of Shenbagavalli and Mahimairaja (2012).

Conclusion

Significant improvement in soil physical properties such as bulk density, porosity, water holding capacity and physico-chemical properties such as pH, CEC was noticed due to biochar addition in the present study. In addition, increase in organic carbon content, SOC storage and organic matter fraction was also observed. Improvement in soil properties synchronized well with the increase in biochar application rate. From its effect on improving the soil quality and sequestering soil C, biochar can be recommended as a modifier in the tropical acidic lateritic soils for improving soil health.

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