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Impact of recycling of mulberry stalk as Biochar for improving soil condition of mulberry cultivated soil

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Abstract
The large quantities of biomass residues, which should be considered as valuable residues, are disposed or burned and reasons unaffordable ecological issues and notable soil degradation. Recycling of biomass by converting it as a useful source of soil amendment is one of way to manage soil health and fertility. The conversion of valuable biomass into biochar could help to mitigate CO_2 emission and increase the carbon sequestration in the soil for sustainable climate-smart agriculture. Biochar addition to soil has attracted widespread attention as a method to sequester carbon in soil. Increased soil carbon sequestration can improve soil quality because of the vital role that carbon plays in physical, chemical and biological soil processes and many interfacial interactions. To further evaluate the influence of biochar application on soil fertility, a field experiment was conducted in the farmer's field at Sidlaghatta (TQ), Chikkaballapur District. The data revealed that, the mulberry stalk biochar has recorded the bulk density of 0.32 Mg m^{-3} and water holding capacity of 93.14 percent. The chemical composition of biochar found to be alkaline in nature with a pH of 8.53 and the electrical conductivity of 0.39 dS m^{-1}. The total carbon content of 69.37 percent was noticed, the nitrogen, phosphorus and potassium recorded at 0.89, 0.22 and 0.65 percent, respectively and also good amount of calcium, magnesium, and sulphur with the tune of 0.96, 0.48 and 0.18 percent, respectively. Biochar also recorded appreciable quantities of iron, zinc, manganese, copper and boron to an extent of 493, 34.59, 94.1, 20.55 and 33.5 mg kg^{-1}. Application of biochar improved the physical, chemical and biological properties of the soil. The findings revealed that utilization of mulberry stalk as a biochar has positive effect on improving soil fertility and it reduce replace chemical fertilizers and promote organic farming in a circular economy concept of recycling the waste.

Keywords: Biochar, soil health, soil properties, C sequestration

1. Introduction
Traditionally, the majority of plant residues, which are removed from the field after harvesting, are usually used as animal feed, biofuel and biomass. In most cases, the crop residue is either burned or discarded, resulting in resources wastage and environmental pollution. Reasonable utilization of the crop residues is very important for sustainable agricultural production. Although it has become the first choice, returning the residues to the soil is very difficult for the case of large-scale production. There is urgent need to intensify agricultural production to secure food supply for the increasing population especially in the tropics. But, the organic matter is mineralized at a faster rate due to high temperature (32-44 ^{0}C) throughout the year except in winter season. In recent years, carbonizing waste agricultural residue into biochar has become a new approach of residue utilization.
Biochar is a source of organic amendment that is receiving attention by researchers all over the world (Lehmann *et al*., 2003) [16]. The process of biochar production is known as pyrolysis and it results in a very stable carbon (C) rich material not only capable of improving physical and chemical soil properties but also increasing soil C storage on a large scale. Among soil organic amendments, biochar is considered as a more stable nutrient source than others (Chan *et al*., 2007) [8]. Organic C content in biochar has been reported up to 90 percent depending upon its feedstock, which enhances C sequestration in soil.
It creates a recalcitrant soil carbon pool that is carbon-negative, serving as a net withdrawal of atmospheric carbon dioxide that is stored in highly recalcitrant soil carbon stocks. According to Steiner *et al*. (2007) [23] improves plant growth by improving the physical and chemical characteristics of the soil, *viz.*, cation exchange capacity, water holding capacity and permeability as well as biological properties.

Moreover, due to the ability of biochar to persist in the soil over a long period of time as it is recalcitrant to decomposition (Major *et al*., 2010) [8]. In view of this, the current study was undertaken to assess the "Impact of recycling of mulberry stalk as biochar for improving soil condition of mulberry cultivated soil".

2. Material and methods

The experiment was carried on farmer's field at Sidlaghatta (TQ), Chikkaballapur District, Karnataka, India, which falls under Eastern Dry Zone of Karnataka (Agro climatic Zone No. 5) and is situated at 13° 36' North latitude 77° 43.49' East longitude and at an altitude of 915 meters above the mean sea level. The experiment was laid out in randomized complete block design and replicated thrice with 8 treatments, where mulberry (Victory V1 variety) was taken as test crop. The treatment details are given below.

T_1: Control (NPK alone)
T_2: POP (FYM (25 t ha^{-1}) + N P_2O_5 K_2O 375:140:140 kg ha^{-1})
T_3: Soil application of biochar @ 5 t ha^{-1}
T_4: Soil application of biochar @ 7.5 t ha^{-1}
T_5: Soil application of biochar @ 10 t ha^{-1}
T_6: Soil application of biochar @ 5 t ha^{-1} + FYM @ 10 t ha^{-1}
T_7: Soil application of biochar @7.5 t ha^{-1} + FYM @ 10 t ha^{-1}
T_8: Soil application of biochar @ 10 t ha^{-1} + FYM @ 10 t ha^{-1}
NPK is common from T_3 to T_8 treatments

A composite surface soil sample (0-15 cm depth) was collected before the commencement of the experiment. The soil of the experimental plot was sandy loam in nature, with a pH of 6.64 and electrical conductivity was 0.21 dS m^{-1}. The initial soil status of the experimental site is presented in Table 1.

Table 1: Initial physico-chemical and biological properties of the soil at experimental site

Parameters	Value
Textural class	Sandy loam
Bulk density (Mg m^{-3})	1.34
Maximum water holding capacity (%)	32.60
Aggregate stability (%)	52.53
Soil pH	6.64
Electrical conductivity (dS m^{-1})	0.21
Organic carbon (%)	0.40
CEC (cmol (p^+) kg^{-1})	15.28
Urease activity (µg NH_4^+-N g^{-1} soil h^{-1})	55.44
Dehydrogenase (µg TPF g^{-1}soil 24 h^{-1})	47.50
Phosphatase (µg PNP g^{-1} soil h^{-1})	26.36

3. Production of biochar

The mulberry stalk generated as waste residue after leaf harvest in the farmer's field was collected and air dried the mulberry stalks. The stalks were chopped uniformly and fumigated over night for production of carbonated material (farmers practice). After carbonization, the biochar was collected and ground to fine powder and used for present investigation in the field.

4. Characterization of biochar

The biochar was characterised by various standardized analytical procedures for its specific physico-chemical properties such as bulk density, water holding capacity, pH, EC and total elements composition. The powdered mulberry stalk biochar was tested for various chemical parameters and findings are shown in Table 2.

Table 2: Characterization of physico-chemical properties of mulberry stalk biochar

Physical properties	
Parameters	Value
Bulk density (Mg m^{-3})	0.32
WHC (%)	93.14
Chemical properties	
pH (1:10)	8.53
EC (1:10) dS m^{-1}	0.39
C (%)	69.37
N (%)	0.89
C/N ratio	42.34
P (%)	0.22
K (%)	0.65
Ca (%)	0.56
Mg (%)	0.39
S (%)	0.18
Fe (mg kg^{-1})	493
Mn (mg kg^{-1})	94.1
Zn (mg kg^{-1})	34.59
Cu (mg kg^{-1})	20.55
B (mg kg^{-1})	33.5

The data shown in Table 2 revealed that, the mulberry stalk biochar has recorded the bulk density of 0.32 Mg m^{-3} and water holding capacity of 93.14 percent. The chemical composition of biochar found to be alkaline in nature with a pH of 8.53 and the electrical conductivity of 0.39 dS m^{-1}. The total carbon content of 69.37 percent was recorded, the nitrogen, phosphorus and potassium recorded at 0.89, 0.22 and 0.65 percent, respectively. It aslo recorded good amount of calcium, magnesium, and sulphur with the tune of 0.96, 0.48 and 0.18 percent, respectively. It also recorded appreciable quantities of iron, zinc, manganese, copper and boron to an extent of 493, 34.59, 94.1, 20.55 and 33.5 mg kg^{-1}, indicating sustainability for improving physic-chemical properties in the soil.

5. Results and Discussion

5.1 Effect of mulberry stalk biochar on physical properties of soil at harvest of mulberry

Results pertaining to soil physical properties *viz.,* bulk density (BD), maximum water holding capacity (MWHC) and aggregate stability as influenced by levels of biochar application in combination with FYM at harvest of mulberry is presented in Table 3.

5.1.1 Bulk density (Mg m^{-3})

The data presented in Table 3 indicated that bulk density of surface soil was significantly influenced with the application of different levels of biochar with FYM. The results revealed that application of different levels of biochar in combination with FYM significantly decreased the values of soil bulk density (BD) at harvest of crop over absolute control (T_1) and POP (FYM @ 25 t ha^{-1} + NP_2O_5 K_2O 350:140:140 kg ha^{-1}) (T_2). Lower values of soil BD were recorded in the treatment which received combined application of biochar and FYM compared to individual application of different levels of biochar. Among different treatments, combination of biochar @ 10 t ha^{-1} + FYM @ 10 t ha^{-1} (T_8) recorded significantly lower soil BD (1.29 Mg m^{-3}) followed by T_7 (1.29 Mg m^{-3}), T_6 (1.29 Mg m^{-3}) and T_5 (1.30 Mg m^{-3}). Significantly, higher BD of 1.32 Mg m^{-3} was recorded in the POP (FYM @ 25 t ha^{-1} + NP_2O_5 K_2O 350:140:140 kg ha^{-1}).

The reduction in bulk density with application of biochar might be due to increase in organic carbon content. Reduction in bulk density of the soils might be the direct result of biochar addition, as biochar itself is a low density material. Nelissen *et al*. (2015) [20] also observed the same finding in their research that bulk density decreased from 1.47 to 1.44 Mg m^{-3} and porosity was increased from 0.43 to 0.44 m^3 m^{-3}. Adekiya *et al*. (2018) [1] also showed the same results of decreased bulk density after addition of biochar with organic manure. Busscher *et al*. (2011) [7] who reported that increasing total organic carbon by the addition of organic amendments in soils could significantly decrease bulk density. Ulyett *et al.* (2014) [27], Aslam *et al*., (2014) [3] and Esmaeelnejad *et al*., (2016) [12], supported significant reduction in bulk density of soil supplied with biochar due to low density and more resistance to compression of biochar than soil. Addition of biochar made the soil porous, increase in the pore volume and organic matter content and compression resistance and all those accounted for lower bulk density

5.1.2 Maximum Water Holding Capacity (MWHC)

Maximum water holding capacity (MWHC) of soil was significantly influenced with the increasing rate of biochar with FYM application. At harvest stage, maximum MWHC of 37.08 per cenr was recorded in the treatment T_8 (biochar @ 10 t ha^{-1} + FYM @ 10 t ha^{-1}) and it was on par with the treatment T_7 (36.44%) which received soil application of biochar @ 7.5 t ha^{-1} and FYM @ 10 t ha^{-1} and it was superior over T_1 (31.57%) control and T_2 (32.67%) POP treatments.

The results showed increased water holding capacity for biochar amended soil compared to the unamended soils because of its sponge in nature. This implies to more water retention within the biochar and also due to the reduced soil bulk density, increased aggregation and the soil organic matter content. The water holding capacity of the soil was increased with biochar application because biochar tends to increase the soil's specific surface area, extensive pore structure and more total porosity (macro and micro pores). Increase in water holding capacity with the addition of biochar was due to the changes in soil structure, increase in porosity and capillary function was reported by Sun *et al.* (2013) [25].

Table 3: Effect of mulberry stalk biochar on bulk density, maximum water holding capacity and aggregate stability of soil at harvest of mulberry

Treatments	Bulk density (Mg m^{-3})	MWHC (%)	Aggregate stability (%)
T_1: Control (NPK alone)	1.33	31.57	52.47
T_2: POP (FYM (25 t ha^{-1}) + NPK 375:140:140 kg ha^{-1})	1.32	32.67	53.57
T_3: Soil application of biochar @ 5 t ha^{-1}	1.31	34.63	55.53
T_4: Soil application of biochar @ 7.5 t ha^{-1}	1.30	34.95	56.40
T_5: Soil application of biochar @ 10 t ha^{-1}	1.30	35.43	57.50
T_6: Soil application of biochar @ 5 t ha^{-1} + FYM @ 10 t ha^{-1}	1.29	35.93	58.53
T_7: Soil application of biochar @7.5 t ha^{-1} + FYM @ 10 t ha^{-1}	1.29	36.44	59.40
T_8: Soil application of biochar @ 10 t ha^{-1} + FYM @ 10 t ha^{-1}	1.29	37.08	60.13
S.Em±	0.007	0.30	0.40
CD@ (5%)	0.02	0.91	1.21

5.1.3 Aggregate stability (%)

The data pertaining to the effect of application of biochar on the aggregate stability of soil is presented in Table 3. The results indicated that with application of biochar in combination with FYM increased the aggregate stability of soil over control. The highest aggregate stability (60.13%) was recorded in the treatment which received biochar @ 10 t ha^{-1} + FYM 10 t ha^{-1} followed by T_7 which received biochar @ 7.5 t ha^{-1} + FYM 10 t ha^{-1} (59.40%) and these are on par with each other and found superior over other treatments. The lowest aggregate stability (52.47%) was recorded in control with no biochar application.

Biochar and FYM addition to soil decreased the bulk density of the soil and enhancing soil porosity and aggregate formation in sandy or loamy soil. This could be due to application of organic carbon in the form of FYM and biochar and act as cementing materials in forming stable soil aggregates. The formation and stability of the soil aggregates play an important role in the crop production and prevention of soil degradation. The capacity of soil aggregation increased from 8 to 36 percent after the application of rice husk biochar (RHB) and rice husk biochar could increase soil pore structure by 20 percent. An increase in the formation of macroaggregates by the addition of RHB indicates that the RHB is able to increase the soil aggregation. Addition of a 6 percent RHB reduced the percentage of microaggregates from 70.9 percent to 50.4 percent, suggesting that the macroaggregates were formed by the coalescence of many microaggregates. The carbon introduced by the RHB may act like a glue to cement microaggregates into macroaggregates in which larger pore spaces are present between micro-aggregates.

When biochar is incorporated into the soil, it increase the microbial activity and produce mucilaginous gel and there by act as a binding agent that connects soil micro-aggregates to form macro-aggregates. This leads to an increase in the diameter of the soil aggregates of biochar amended soils (Cheng *et al*., 2006) [10] and therefore, changes in pore-size distribution and aggregate stability of soil. Omondi *et al.* (2016) [29] also shows the increase in aggregate stability by 8.2 percent (n=10) after the addition of biochar. It has been suggested that the porous structure of biochar can influence its impact on soil water holding capacity and adsorption capacity. Moreover, biochar particles are known for having more porosity to retain water due to their spherical shape and deformability (Stefan, *et al.*, 2013) [30].

5.2 Effect of mulberry stalk biochar on chemical properties of soil (pH, EC, OC and CEC) at harvest of mulberry

5.2.1 Soil pH

The soil pH increased markedly with application of different levels of biochar in combination with FYM in all the three crops cuttings and is presented in Table 4. Among different treatments, significantly higher (6.79) pH of soil was recorded in treatment T_8 which received biochar @ 10 t ha^{-1} + FYM 10 t ha^{-1} followed by T_7 (biochar @ 7.5 t ha^{-1} + FYM @ 10 t ha^{-1}) (6.76). Lowest pH in the soil (6.65) was observed in the T_1

(control) followed by T_2 (6.63) treatment (POP: FYM @ 25 t ha^{-1} + NP_2O_5 K_2O 350:140:140 kg ha^{-1}).

Increased rate of application of biochar increased the pH of soil. Biochar application is known to increase pH of acidic soils which are base poor soil. The soil pH significantly varied due to application of various rates of biochar. The observed changes in pH of soil applied with biochar can be ascribed to the release of alkaline compounds, and thus alkaline nature of biochar and organic matter oxidation brought about by microbial activity which neutralized and thus increased the soil pH. This result is similar to the work of Uday (2009) [26] on maize crop.

During pyrolysis, cations (primarily K, Ca, Si and Mg) present in the feedstock formed metal oxides and once applied to soil, these oxides can react with H^+ and monomeric Al species leads to the formation of more neutral [Al $(OH)_3$]0 species due to which there will be reduction of readily hydrolyzable monomeric Al, thereby increasing the pH of the soil (Novak *et al*., 2009) [21] thus alleviate soil pH. As biochar contain significant quantity of Ca, it can replace the monomeric Al species from soil exchange complex in acidic soil (Novak *et al*., 2009) [21]. As the soil pH increases, the soluble and exchangeable Al^{3+} precipitates as insoluble hydroxyl Al-species. The Al concentration can be reduced drastically by addition of biochar that acts as a liming agent in most of the degraded soils (Glaser *et al*., 2002; Major *et al*., 2010) [13, 8]. The inorganic carbonate and organic anion contribution of biochar can cause an increase in the soil pH.

5.2.2 Electrical Conductivity (EC) dS m^{-1}

The data pertaining to the effect of application of biochar on electrical conductivity of soil is presented in Table 4. Application of biochar in combination with FYM increased the EC of soil over control. The highest EC (0.36 dS m^{-1}) was recorded in the treatment which received biochar @ 10 t ha^{-1} + FYM 10 t ha^{-1} followed by (T_7) which received biochar @ 7.5 t ha^{-1} + FYM 10 t ha^{-1} (0.34 dS m^{-1}) and these are on par with each other and found superior over other treatments. The lowest EC (0.24 dS m^{-1}) was recorded in control with no biochar application.

The increased soil electrical conductivity might be because of biochar application which is alkaline in reaction with more salt content. Application of biochar at 10 t ha^{-1} + FYM @ 10 t ha^{-1} recorded significantly higher EC value whereas, lower EC was observed in control where no biochar was applied. This trend in electrical conductivity might be due to mineralization of biochar which could release different salts and might have resulted an increase in salt content reflecting in increased electrical conductivity. Slight increase in soil EC by the combined application of biochar and FYM might be due to result of the dissolution of native salts due to the activity of microbial consortium. Similar observations were made by Bandara *et al*. (2015) [6].

Incorporation of biochar to soil caused an increase in EC due to the release of weakly bound nutrients (cations and anions) of biochar into the soil solution, which are available for plant uptake (Chintala *et al*., 2014; Glaser *et al*., 2002; Gundale and DeLuca 2007; Chan *et al*., 2008) [13]. An increase in EC of soil due to application of biochar are generally dominated by carbonates of alkali, silica, phosphates and small amounts of organic and inorganic N.

5.2.3 Organic carbon (OC)

The data pertaining to the organic carbon content is presented in Table 4. Organic carbon content of soil markedly increased among the treatments over the initial value.

Significantly higher organic carbon content of 0.58 percent was recorded in the treatment T_8 which received biochar @ 10 t ha^{-1} + FYM @ 10 t ha^{-1} and it was on par with T_7 (0.56%) and T_6 (0.55%) treatments but superior over other treatments. Treatment (T_5) which received biochar @ 10 t ha^{-1} recorded significantly higher organic carbon content (0.53%) and it was at par with the treatment T_4 (0.52%) and T_3 (0.51%) and it was superior to T_2 (0.50%) and T_1 (0.49%).

Higher values of soil organic carbon were found in biochar treated plots over non-biochar. It might be due to the reason that biochar is a mixture of two carbon components one which degrades readily (labile fraction) and second is more recalcitrant fraction. The highest values of organic carbon in biochar treated soils indicate the recalcitrance of organic carbon in biochar.

Addition of biochar along with FYM increased the organic carbon content of soil. The organic amendments add organic matter to the soil and their subsequent decomposition increase organic carbon status of the soil. Li *et al*. (2015) also observed an increase in organic carbon after the application of biochar. Also it could be explained by the fact that the porous structure, high CEC and high surface area of biochar make it more stable carbon content. Similar results were in line with the findings of Sukartono *et al*. (2011) [24] who reported that the biochar application improved soil fertility status in soil, especially soil organic carbon. Also reported by Sara *et al*. (2018) [22], soil organic carbon was considerably better in the biochar treated plots than in the control.

Table 4: Effect of mulberry stalk biochar on pH, EC, OC and CEC of soil at harvest of mulberry

Treatments	pH	EC (dS m^{-1})	OC (%)	CEC [cmol (p^+) kg^{-1}]
T_1: Control (NPK alone)	6.65	0.24	0.49	15.15
T_2: POP (FYM (25 t ha^{-1}) + NPK 375:140:140 kg ha^{-1})	6.63	0.25	0.50	15.27
T_3: Soil application of biochar @ 5 t ha^{-1}	6.70	0.29	0.51	16.37
T_4: Soil application of biochar @ 7.5 t ha^{-1}	6.71	0.30	0.52	17.03
T_5: Soil application of biochar @ 10 t ha^{-1}	6.73	0.31	0.53	17.37
T_6: Soil application of biochar @ 5 t ha^{-1} + FYM @ 10 t ha^{-1}	6.75	0.33	0.55	18.05
T_7: Soil application of biochar @7.5 t ha^{-1} + FYM @ 10 t ha^{-1}	6.76	0.34	0.56	18.75
T_8: Soil application of biochar @ 10 t ha^{-1} + FYM @ 10 t ha^{-1}	6.79	0.36	0.58	19.18
S.Em±	0.008	0.01	0.01	0.35
CD@ (5%)	0.02	0.03	0.03	1.07

5.2.4 Cation Exchange Capacity (CEC)

The data (Table 4) clearly showed that there is significant variation in the CEC of soil due to the effect of levels of biochar and FYM and their combinations. Among the different treatments, higher CEC value (19.18 cmol (p^+) kg^{-1}) was recorded in the treatment (T_8) which received biochar application @ 10 t ha^{-1} + FYM @ 10 t ha^{-1} followed by T_7 (18.75 cmol (p^+) kg^{-1}, respectively) which received biochar @ 7.5 t ha^{-1} + FYM @ 10 t ha^{-1}. However, the treatments T_4, T_5 and T_6 which received soil application of biochar @ 5, 7.5 and 10 t ha^{-1}, respectively recorded significantly higher CEC value compared to treatments T_2 and T_1.

Biochar generally have higher charge densities when produced at higher pyrolysis temperatures (Glaser *et al*., 2002) [13]. Increase in the CEC of biochar treated plots might be due to high surface area of biochar that resulted an increase in exchange sites. As biochar formed the organo-mineral complexes, the soil treated with biochar might have increased the CEC. Significant increase in the CEC with addition of biochar was repoted by Ulyett *et al*. (2014) [27].

Biochar application boosts up the soil fertility and improves soil quality by raising soil pH, improving cation exchange capacity and nutrient retention in soil (Chan *et al.*, 2007). Slight increase in the CEC on FYM addition might be due to decomposition of FYM in the soils and form humus and humic substances which increases the CEC. The same result was obtained by Adeniyan *et al*. (2011).

5.3 Effect of mulberry stalk biochar on biological properties of soil (urease, dehydrogenase and phosphatase activity) at harvest of mulberry

5.3.1 Urease activity

The perusal data on urease activity influenced by combined application of biochar and FYM is presented in Fig. 1. Urease activity significantly differed with different treatments.

The lower urease activity was recorded in control and increased significantly due to combined application of biochar and FYM. Combined soil application of biochar @ 10 t ha^{-1} and FYM @ 10 t ha^{-1} recorded higher urease activity (64.54 µg NH_4^+-N g^{-1} soil h^{-1}) and it was on par (63.65 µg NH_4^+-N g^{-1} soil h^{-1}) with the treatment T_7 which received soil application of biochar @ 7.5 t ha^{-1} and FYM @ 10 t ha^{-1} and it was superior to rest of the treatments.

Higher urease activity in soils treated with biochar addition might be due to the increase in oxidative capacity of soil microorganisms and the hydrolysis reactions of urea. Also it may be due to increase of enzymes activity with addition of organic carbon through FYM and biochar to the soil. The increase in organic C content activates the urease enzyme in soils. Similar results were observed by Du *et al*. (2014). The present research results are also in conformity with those of Hammes and Schmidt (2009) [15].

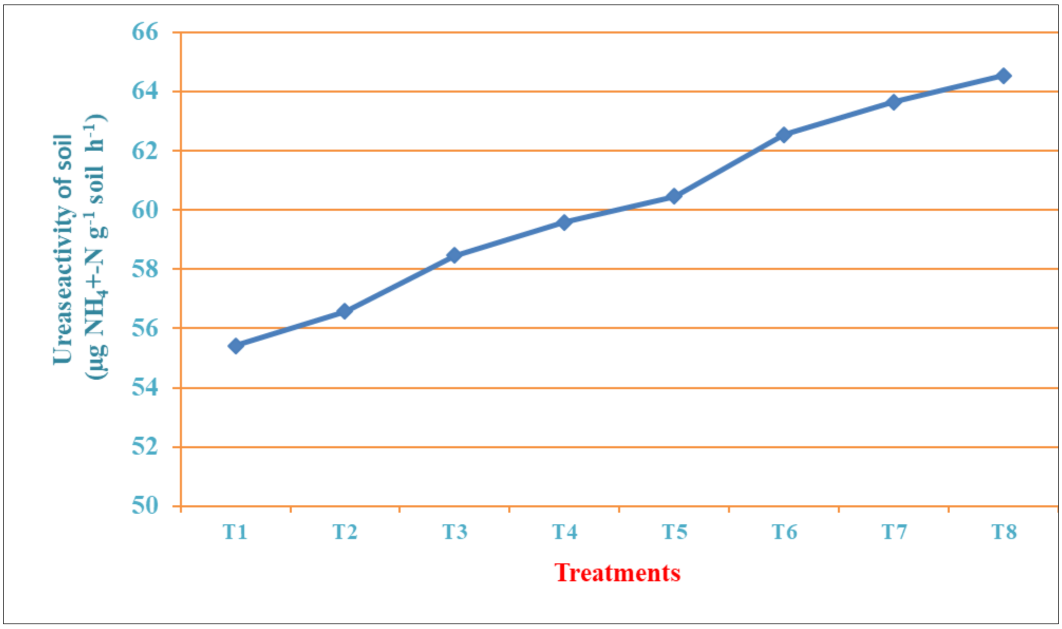

Fig 1: Effect of mulberry stalk biochar on urease activity of soil at harvest of mulberry

5.3.2 Dehydrogenase activity

Application of FYM, and different levels of biochar significantly influenced the dehydrogenase activity and the values ranged from 47.13 to 57.28 µg TPF g^{-1} soil 24 h^{-1} (Fig. 2).

The data showed marked significant differences with respect to dehydrogenase activity and the highest dehydrogenase activity was being recorded in T_8 (57.28 µg TPF g^{-1} soil 24 h^{-1}) and the next best treatment was T_7 (56.09 µg TPF g^{-1} soil 24 h^{-1}) while the lowest value was recorded in control (47.13 µg TPF g^{-1} soil 24 h^{-1}). Application of higher dose of biochar along with FYM increased the dehydrogenase activity. This is mainly due to an increase in enzymes activity with addition of organic carbon through FYM and application of biochar to the soil. Because biochar has porous nature, high surface area and its ability to adsorb soluble organic matter and inorganic nutrients, provides a highly suitable habitat for microbes and enzymes. Marinara *et al*. (2006) [19] suggested that higher dehydrogenase activity is due to higher metabolic activity of microorganisms in FYM applied treatment in combination with biochar treatments and soil organic carbon contents may potentially explain increased enzyme activities.

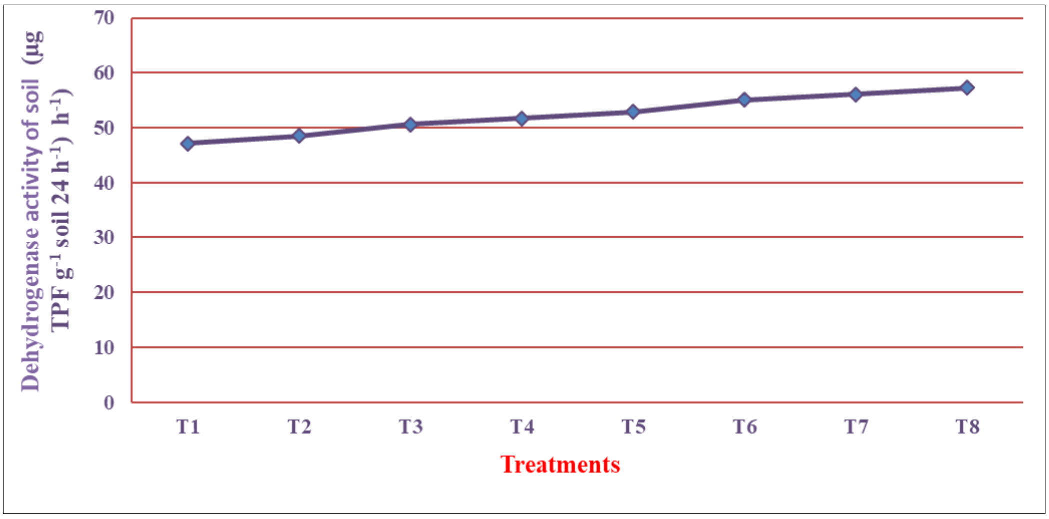

Fig 2: Effect of mulberry stalk biochar on dehydrogenase activity of soil at harvest of Mulberry

5.3.3 Phosphatase activity

The results pertaining to phosphatase activity in relation to different treatments is presented in Fig. 3. The effects of the different treatments have significant impact on phosphatase activity. The phosphatase activity was found higher under treatment when biochar was applied with the combination of FYM as compared to sole application of biochar. The highest phosphatase activity in soil (35.35 µg PNP g^{-1} soil h^{-1}) was recorded under the treatment (T_8) with biochar application @ 10 t ha^{-1} + FYM @ 10 t ha^{-1} followed by T_7 (34.24 µg PNP g^{-1} soil h^{-1}) which received biochar @ 7.5 t ha^{-1} + FYM @ 10 t ha^{-1} while, the minimum phosphatase activity in soil (26.37 µg PNP g^{-1} soil h^{-1}) was recorded under control (T_1). However, the treatments T_4, T_5 and T_6 which received soil application of biochar @ 5, 7.5 and 10 t ha^{-1}, respectively recorded significantly higher phosphatase activity compared to treatments T_2 and T_1.

The higher values of phosphatase enzyme activity are recorded with higher rate of biochar application in combination with FYM. Marinara *et al*. (2006) [19] also reported that higher soil organic carbon contents may potentially explain increased enzyme activities. It is also due to the fact that due to addition of both biochar and FYM, there was a better root growth that contributed for higher phosphatase activity and it is well known that phosphatase are mainly root originated. The increased pH values in the original low pH soil could also enhance the availability of nutrients and consequently increase soil microbial biomass (Atkinson *et al*., 2010; Warnock *et al*., 2010) [4, 28]. Activities of certain enzymes like, alkaline phosphatase, aminopeptidase and N- acetyl glucosaminidase have been reported to increase due to biochar application (Bailey *et al*., 2010) [5].

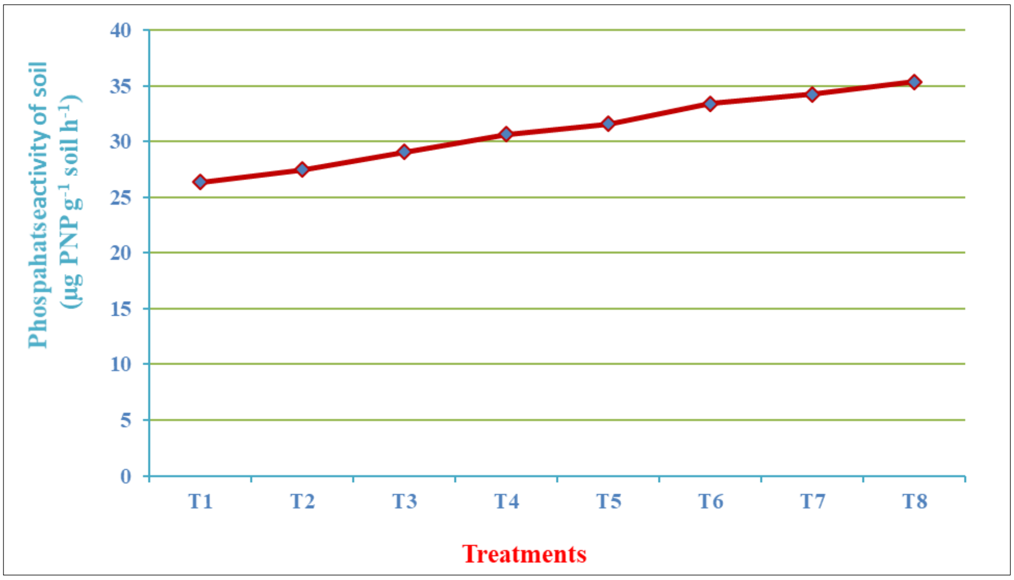

Fig 3: Effect of mulberry stalk biochar on phosphatase activity of soil at harvest of mulberry

6. Conclusion

Application of biochar significantly influenced the physicochemical and biological properties of the soil. Compared with NPK and POP treatments, combined application of biochar and FYM significantly decreased soil bulk density and increased MWHC, aggregate stability, pH, EC, OC, CEC, urease, dehydrogenase and phosphatase activity of the soil. These positive changes in the biochar-applied soil increase and regulate the nutrient availability. Further application of biochar from crop residues, may offer additional carbon-negative benefits by avoiding burning in field and bio resource recycling, which have been a great concern with air pollution of Indian agriculture and climate change mitigation.

7. References

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