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Enhancing Soil Fertility of Mulberry Cultivated Garden through Sustainable Recycling of Mulberry Stalks as Biochar Adjunct with Organic Amendments

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ABSTRACT

A field experiment was conducted in the farmer's field at Mylandlahalli of Chintamani (Taluk), Chikkaballapur (District) to enhance soil fertility of mulberry cultivated garden through sustainable recycling of mulberry stalks as biochar adjunct with organic amendments. Experiment consisted of 8 treatments with three replications laid out in Completely Randomized Block Design. The data revealed that, highest aggregate stability (58.80%) and maximum water holding capacity of 33.79 per cent 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} and T_6 biochar @ 5 t ha^{-1} + FYM 10 t ha^{-1}, these are on par with each other and found superior over other treatments. The lowest aggregate stability (50.92%) and maximum water holding capacity (31.16%) was recorded in control with no biochar application. Similarly, application of biochar @ 10 t ha^{-1} + FYM 10 t ha^{-1} recorded significantly higher soil reactivity, electrical conductivity and cation exchange capacity followed by soil application of biochar @ 7.5 and 5 t ha^{-1} + FYM @ 10 t ha^{-1}. Lower values for chemical properties were recorded in control treatment. Application of biochar @ 10 t ha^{-1} + FYM 10 t ha^{-1} recorded higher available nitrogen (313.82 kg ha^{-1}), available phosphorus (50.41 kg ha^{-1}) and available potassium (240.96 kg ha^{-1}). Soil biological properties also recorded higher with the application of biochar @ 10 t ha^{-1} + FYM 10 t ha^{-1}. Control treatment recorded lower major available nutrients and enzymatic activity in the soil.

Keywords : Biochar, FYM, Soil fertility, Mulberry

MULBERRY cultivation has long been a cornerstone of various industries, playing a crucial role in sericulture and providing a sustainable source of livelihood for many communities. As the demand for mulberry products continues to rise, so does the production of mulberry stalks, an often-overlooked byproduct of this industry. Traditionally, these stalks are considered agricultural waste and are disposed of without recognizing their potential utility. However, as global awareness of sustainable agricultural practices grows, there is a pressing need to explore innovative ways to manage agricultural residues. The focus of this study is to investigate how mulberry stalks, typically considered a discarded resource, can be transformed into biochar through a sustainable process of pyrolysis. Biochar, a stable carbon-rich material, has garnered attention in recent years for its potential to enhance soil properties and contribute to long-term soil fertility. The conversion of mulberry stalks into biochar not only addresses the challenge of waste management but also aligns with the broader goals of promoting sustainable agriculture and mitigating environmental impact.

Mulberry stalks, being rich in carbon and other organic compounds, have the potential to serve as a valuable feedstock for biochar production. The pyrolysis of mulberry stalks into biochar involves heating the biomass in the absence of oxygen, resulting in the transformation of the organic material into a stable and highly porous carbon structure. This biochar, when incorporated into the soil, has been reported to improve soil structure, water retention and nutrient availability. The current state of soil health, especially in mulberry-cultivated areas, necessitates a shift toward sustainable soil management practices. Soil degradation, loss of fertility and the decline in organic matter content are pressing issues that require innovative solutions. The sustainable recycling of mulberry stalks as biochar presents an opportunity not only to address the challenges posed by agricultural waste but also to actively contribute to the restoration and enhancement of mulberry-cultivated soil.

This research aims to comprehensively explore the impact of mulberry biochar on soil fertility and crop performance. By conducting rigorous analyses of soil properties, nutrient cycling and crop yields, we seek to unravel the intricate interactions between mulberry biochar and the soil environment. The ultimate goal is to provide evidence-based insights into the feasibility and efficacy of incorporating mulberry biochar into mulberry-cultivated soil systems. As we embark on this journey of exploring the sustainable recycling of mulberry stalks as biochar, we anticipate that the findings will not only contribute to the scientific understanding of soil-biochar interactions but also offer practical solutions for farmer's and stakeholders in the mulberry industry. By bridging the gap between waste management and soil enhancement, this research endeavors to pave the way for a more sustainable and resilient future for mulberry cultivation.

MATERIAL AND METHODS

The experiment was conducted on a farmer's field located in Mylandlhalli Village Chintamani taluk, Chikkaballapur district, Karnataka, India. This region is part of the Eastern Dry Zone of Karnataka, which is designated as Agroclimatic Zone No. 5. The field is situated at 13° 36' North latitude and 77° 43.49' East longitude, with an altitude of 915 meters above mean sea level. The experiment was designed using a randomized complete block design, replicated three times and consisted of eight treatments. Mulberry (Victory V1 variety) was chosen as the test crop for the study. The treatment details are provided below:

Treatments	Details
T_1	Control (N:P_2O_5:K_2O 350:140:140 kg ha^{-1})
T_2	POP (FYM (25 t ha^{-1}) + N:P_2O_5:K_2O 350:140:140 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}

A surface soil sample (0-15 cm depth) was collected before the experiment began. The soil of the experimental plot was sandy loam with a pH of 6.64 and an electrical conductivity of 0.21 dS m^{-1} at 25°C. The initial soil status of the experimental site is presented in Table 1.

Production of Biochar

The mulberry stalk generated as waste residue after leaf harvest in the farmer's field was collected and air dried. Producing biochar from mulberry stalks *via.,* pyrolysis is an eco- friendly process. Mulberry stalks, a readily available agricultural byproduct, are first prepared by cutting them into uniform pieces. These prepared stalks are loaded into a pyrolysis unit designed for oxygen-free conditions. The pyrolysis process heats the stalks, breaking them down into biochar (a stable carbon-rich material), bio-oil (a liquid byproduct) and syngas (a gas mixture). After carbonization, the biochar was collected and ground to a fine powder and used for the field experiment

Characterization of Biochar

The biochar was characterised by various standardized analytical procedures for its specific physicochemical properties such as bulk density, water holding capacity,

TABLE 1

Initial physical, chemical and biological properties of soil of the experimental site

Parameter	Value	Method followed
Textural class	Sandy loam	International Pipette method (Piper, 1966)
Bulk density (Mg m^{-3})	1.34	Keen rackzowski method (Baruah and Barthakur, 1997)
Maximum water holding capacity (%)	32.60	
Aggregate stability (%)	52.53	Yoder's apparatus
Soil pH	6.64	Potentiometry (Jackson, 1973)
Electrical conductivity (dS m^{-1})	0.21	Conductometry (Jackson, 1973)
Organic carbon (%)	0.40	Wet oxidation (Walkley and Black, 1934)
CEC (cmol (p$^+$) kg^{-1})	15.28	Sodium acetate method
Available N (kg ha^{-1})	261.37	Alkaline permanganate method (Subbaiah and Asija, 1956)
Available P_2O_5 (kg ha^{-1})	35.84	Bray's extraction method (Bray and Kurtz, 1945)
Available K_2O (kg ha^{-1})	210.26	Flame photometry (Jackson,1973)
Available S (mg kg^{-1})	15.82	Turbidometry extraction method (Black, 1965)
Exchangeable Ca (cmol (p+) kg^{-1})	4.52	Complexometric titration method (Jackson, 1973)
Exchangeable Mg (cmol (p+) kg^{-1})	1.85	
DTPA Fe (mg kg^{-1})	12.66	Atomic AbsorptionSpectrophotometry (Lindsay and Norwell, 1978)
DTPA Zn (mg kg^{-1})	0.83	
DTPA Mn (mg kg^{-1})	4.91	
DTPA Cu (mg kg^{-1})	1.56	
Available B (mg kg^{-1})	0.33	Hot water-soluble extraction method (John *et al.,*1975)
Urease activity (µg NH4+-N g^{-1} soil h^{-1})	55.44	Eivazi and Tabatabai (1977)
Dehydrogenase (µg TPF g^{-1}soil 24 h^{-1})	47.50	TTC reduction technique (Casida, 1964)
Phosphatase (µg PNP g^{-1} soil h^{-1})	26.36	P-nitro phenyl phosphatase method (Eivazi and Tabatabai, 1977)

pH, EC and total elements composition. The powdered mulberry stalk biochar was tested for various chemical parameters and findings are shown in Table 2.

The data presented in Table 2 revealed that the mulberry stalk biochar has recorded a bulk density of 0.34 Mg m^{-3} and a water holding capacity of 95.05 per cent. The chemical composition of biochar was found to be alkaline in nature with a pH of 8.53 and an electrical conductivity of 0.39 dS m^{-1} at 25 °C. The total carbon content of 72.18 per cent was recorded, nitrogen, phosphorus and potassium were recorded at 0.83, 0.35 and 0.98 per cent, respectively. It also recorded a good amount of calcium, magnesium and sulphur with the tune of 0.68, 0.43 and 0.15 per cent, respectively. It also recorded appreciable quantities of iron, zinc, manganese, copper and boron to an extent of 493, 38.68, 98.02, 29.09 and 33.5 mg kg^{-1}, indicating sustainability for improving physic-chemical properties in the soil.

RESULTS AND DISCUSSION

Effect of Mulberry Stalk Biochar on Physical Properties of Soil at Harvest

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 are presented in Table 3.

Bulk Density

The data presented in Table 3 suggests that the application of different levels of biochar with FYM decreased the values of soil bulk density (BD) at harvest of the crop over control (T_1) and POP (FYM

TABLE 2

Characterization of physical and chemical properties of mulberry stalk biochar physical properties

Parameters	Value	Method followed
Bulk density (Mg m^{-3})	0.34	Keen rackzowski method (Baruah and Barthakur, 1997)
WHC (%)	95.05	
Chemical properties		
pH (1:10)	8.53	Potentiometry (Jackson, 1973)
EC (1:10) dS m^{-1}	0.39	Conductometry (Jackson, 1973)
C (%)	72.18	Dry combustion method (CHNS, LECO)
N (%)	0.83	Kjeldahl digestion and distillation method (Piper, 1966)
P (%)	0.35	Diacid digestion and vanadomolybdate method (Piper, 1966)
K (%)	0.98	Diacid digestion and flame photometer method (Piper, 1966)
Ca (%)	0.68	Diacid digestion and Complexometric titration method (Piper, 1966)
Mg (%)	0.43	
S (%)	0.15	Diacid digestion and Turbidometry (Black, 1965)
Fe (mg kg^{-1})	493.00	Diacid digestion and atomic absorption spectrophotometry (Lindsay and Norvell, 1978)
Mn (mg kg^{-1})	98.02	
Zn (mg kg^{-1})	38.68	
Cu (mg kg^{-1})	29.09	
B (mg kg^{-1})	33.50	Azomethine-H method (Page *et al.,* 1982)

TABLE 3

Effect of mulberry stalk biochar and FYM on physical properties of soil at harvest of mulberry

Treatments	BD (Mg m-3)	MWHC (%)	Aggregate stability (%)
T$_1$:Control (N:P2O5:K2O 350:140:140 kg ha^{-1})	1.32	31.16	50.92
T$_2$:POP (FYM (25 t ha^{-1}) + N:P2O5:K2O 350:140:140 kg ha^{-1})	1.28	33.08	55.26
T$_3$: Soil application of biochar @ 5 t ha^{-1}	1.31	32.05	53.81
T$_4$: Soil application of biochar @ 7.5 t ha^{-1}	1.30	32.08	54.17
T$_5$: Soil application of biochar @ 10 t ha^{-1}	1.29	32.44	55.06
T$_6$: Soil application of biochar @ 5 t ha^{-1} + FYM@ 10 t ha^{-1}	1.28	33.30	57.70
T$_7$: Soil application of biochar @ 7.5 t ha^{-1} + FYM @ 10 t ha^{-1}	1.27	33.55	58.33
T$_8$: Soil application of biochar @ 10 t ha^{-1} +FYM @ 10 t ha^{-1}	1.26	33.79	58.80
S.Em ±	0.05	0.87	1.34
CD @ 5 %	NS	0.91	4.08

@ 25 t ha^{-1} + NP$_2$O$_5$K$_2$O 350:140:140 kg ha^{-1}) (T$_2$). The results revealed that lower values of soil BD were recorded in the treatment which received the combined application of biochar and FYM compared to individual application of different levels of biochar. Among different treatments, the combination of biochar @ 10 t ha^{-1} + FYM @ 10 t ha^{-1} (T$_8$) recorded lower soil BD (1.26 Mg m^{-3}) followed by T$_7$ (1.27 Mg m^{-3}) and T$_6$ (1.27 Mg m^{-3}). The control (NPK alone) recorded a higher BD of 1.32 Mg m^{-3}. The reduction in bulk density of the soils might be the direct result of biochar addition, as biochar itself is a low density material. The reduction in bulk density with the application of biochar might be due to an increase in organic carbon content, similar findings were reported by Aslam *et al*., 2014

Maximum Water Holding Capacity

Maximum water holding capacity (MWHC) of soil was significantly influenced by the increasing rate of biochar with FYM application. At the harvest stage, a maximum MWHC of 37.08 per cent was recorded in treatment T_8 (biochar @ 10 t ha^{-1} + FYM @ 10 t ha^{-1}) and it was on par with treatment T_7 (36.44%) which received soil application of biochar @ 7.5 t ha^{-1} with 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 spongy nature. This implies 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 increased with biochar application because biochar tends to increase the soil's specific surface area, extensive pore structure and total porosity (macro and micropores). The increase in water holding capacity with the addition of biochar was due to the changes in soil structure, increase in porosity and capillary function as reported by Sun *et al*. (2013) and Rohitha *et al*. (2021).

Aggregate Stability (%)

The data pertaining to the effect of the 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. 0.91 1.21 The carbon introduced by the RHB may act like a glue to cement microaggregates into macroaggregates in which larger pore spaces are present between microaggregates. Biochar and FYM addition to soil decreased the bulk density of the soil and enhanced soil porosity and aggregate formation in a sandy or loamy soil. This could be due to the application of organic carbon in the form of FYM and biochar which acts as cementing materials in forming stable soil aggregates. The formation and stability of the soil aggregates play an important role in crop production and prevention of soil erosion. The capacity of soil aggregation increased from 8 to 36 per cent after the application of rice husk biochar (RHB) and rice husk biochar could increase soil pore structure by 20 per cent. An increase in the formation of macroaggregates by the addition of RHB indicates that the RHB can increase soil aggregation.

The addition of a 6 per cent RHB reduced the percentage of micro aggregates from 70.9 per cent to 50.4 per cent, suggesting that the macroaggregates were formed by the coalescence of many microaggregates. When biochar is incorporated into the soil, it increases microbial activity and produces mucilaginous gel thereby 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) and therefore, changes in pore-size distribution and aggregate stability of soil. Omondi *et al*. (2016) also show an increase in aggregate stability by 8.2 per cent 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).

Effect of Mulberry Stalk Biochar and FYM on Chemical Properties of Soil (pH, EC, OC and CEC) at Harvest of Mulberry

The application of different levels of biochar in combination with FYM resulted in a significant increase in soil pH as indicated in Table 4. Treatment T_8, which received biochar at a rate of 10 t ha^{-1}

TABLE 4

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

Treatments	pH	EC (dS m^{-1})	OC (%)	CEC[cmol (p+) kg^{-1}]
T_1: Control (N:P_2O_5:K_2O 350:140:140 kg ha^{-1})	6.37	0.25	0.49	14.67
T_2: POP (FYM (25 t ha^{-1}) + N:P_2O_5:K_2O 350:140:140 kg ha^{-1})	6.72	0.31	0.52	16.49
T_3: Soil application of biochar @ 5 t ha^{-1}	6.48	0.28	0.50	15.42
T_4: Soil application of biochar @ 7.5 t ha^{-1}	6.62	0.28	0.51	15.70
T_5: Soil application of biochar @ 10 t ha^{-1}	6.69	0.29	0.52	16.40
T_6: Soil application of biochar @ 5 t ha^{-1} + FYM@ 10 t ha^{-1}	6.86	0.32	0.54	16.61
T_7: Soil application of biochar @ 7.5 t ha^{-1} + FYM @ 10 t ha^{-1}	6.99	0.33	0.57	17.67
T_8: Soil application of biochar @ 10 t ha^{-1} +FYM @ 10 t ha^{-1}	7.06	0.35	0.59	18.73
S.Em ±	0.14	0.01	0.01	0.41
CD @ 5 %	0.42	0.02	0.04	1.24

combined with FYM at 10 t ha^{-1}, recorded the highest pH of 7.06. Following closely were treatments T_7 and T_6, showing a pH of 6.99 and 6.86. The lowest soil pH (6.37) was observed in the control treatment (T_1), followed by T_2 (6.72), which involved the application of POP (FYM at 25 t ha^{-1} + $NP_2O_5K_2O$ 350:140:140 kg ha^{-1}). The increase in biochar application rate correlated with an elevation in soil pH. Biochar is known to raise the pH of acidic and nutrient-poor soils. The observed changes in soil pH with biochar application can be attributed to the release of alkaline compounds, the alkaline nature of biochar and the oxidation of organic matter facilitated by microbial activity, collectively neutralizing and increasing soil pH. This finding aligns with the research conducted by Uday (2009) on maize crops. During pyrolysis, cations like K, Ca, Si and Mg present in the feedstock form metal oxides. Upon application to soil, these oxides react with H^+ ion and monomeric Al species, leading to the formation of more neutral [Al(OH)3] species. This process reduces readily hydrolyzable monomeric Al, resulting in an increase in soil pH (Novak *et al.*, 2009). Biochar, containing a significant amount of Ca, can replace monomeric Al species in the soil exchange complex, contributing to the reduction of Al concentration. As the soil pH rises, soluble and exchangeable Al^{3+} precipitates as insoluble hydroxyl Al-species. The addition of biochar acts as a liming agent in degraded soils, significantly reducing Al concentration (Glaser *et al.*, 2002; Major *et al.*, 2010 and Rohitha *et al.*, 2021). The inorganic carbonate and organic anion components of biochar contribute to an increase in soil pH.

Electrical Conductivity

The impact of biochar application on soil electrical conductivity (EC) is presented in Table 4. The combined application of biochar with FYM resulted in an increase in soil EC compared to the control. The treatment receiving biochar at 10 t ha^{-1} + FYM at 10 t ha^{-1} recorded the highest EC at 0.35 dS m^{-1} at 25°C, followed by treatment T_7 and T_6 with biochar at 7.5 and 5 t ha^{-1} + FYM at 10 t ha^{-1}, showing a similar and superior value of 0.33 and 0.32 dS m^{-1} compared to other treatments. The control, with no biochar application, exhibited the lowest EC at 0.25 dS m^{-1} at 25°C. The elevated soil electrical conductivity is likely attributed to the alkaline nature of biochar and its potential to increase salt content. The application of biochar at 10 t ha^{-1} + FYM at 10 t ha^{-1} resulted in a significantly higher EC, while the control exhibited a lower EC due to the absence of biochar. This trend in electrical conductivity may be linked to the mineralization of biochar, leading to the release of various salts and subsequently increasing salt content, as reflected in the elevated electrical conductivity. The combined application of biochar and FYM may also contribute to a slight increase in soil EC, possibly due to the dissolution of native salts facilitated by the activity of microbial consortium. Similar findings were reported by Bandara *et al.* (2015). The incorporation of biochar into the soil leads to an increase in EC, primarily due to the release of weakly bound nutrients (cations and anions) from biochar into the soil solution, making them available for plant uptake. This increase in soil EC with biochar application is commonly associated with carbonates of alkali, silica, phosphates and small amounts of organic and inorganic nitrogen (Chintala *et al.*, 2014; Glaser *et al.*, 2002; Gundale and DeLuca, 2007; Chan *et al.*, 2008 and Fasiha & Devakumar, 2022).

Organic Carbon

The data presented in Table 4 reveals variations in the organic carbon content of the soil across different treatments, indicating a marked increase compared to the initial values. Treatment T_8, receiving biochar at 10 t ha^{-1} + FYM at 10 t ha^{-1}, exhibited a significantly higher organic carbon content of 0.59 per cent. This result was comparable to T_7 (0.57%) and T_6 (0.54%) but superior to other treatments. Treatment T_5, with biochar at 10 t ha^{-1}, recorded a significantly higher organic carbon content of 0.52 per cent, on par with T_4 (0.51%) and T_3 (0.50%) and superior to T_1 (0.49%). Biochar treated plots consistently showed higher soil organic carbon values compared to non-biochar treated plots, indicating the presence of a mixture of two carbon components in biochar one that readily degrades (labile fraction) and another more recalcitrant fraction. The elevated organic carbon values in biochar-treated soils highlight the recalcitrance of organic carbon in biochar. The addition of biochar alongside FYM resulted in an increase in soil organic carbon content. Organic amendments, including biochar, contribute organic matter to the soil and their subsequent decomposition enhances the organic carbon status of the soil. This finding aligns with Li *et al.* (2015), who also observed an increase in organic carbon in soil after biochar application.

The porous structure, high cation exchange capacity (CEC) and large surface area of biochar contribute to its stable carbon content. These results are consistent with Sukartono *et al.* (2011), who reported improved soil fertility, particularly in soil organic carbon, with biochar application. Rohitha *et al.* (2021) also noted significantly better soil organic carbon levels in biochar-treated plots compared to the control.

Cation Exchange Capacity (cmol (p+) kg^{-1})

The data presented in Table 4 highlights significant variations in the cation exchange capacity (CEC) of the soil attributed to the different levels of biochar and FYM, as well as their combinations. Treatment T_8, receiving biochar at 10 t ha^{-1} + FYM at 10 t ha^{-1}, exhibited significantly higher CEC value at 18.73 cmol (p+) kg^{-1}, followed by T_7 and T_6 with 17.67 and 16.61 cmol (p+) kg^{-1}, demonstrating the effectiveness of this combination. Treatments T_4, T_5 and T_6, with biochar at 5, 7.5 and 10 t ha^{-1}, respectively, recorded significantly higher CEC values compared to T_1. Biochar, especially when produced at higher pyrolysis temperatures, tends to have higher charge densities and the increased CEC in biochar-treated plots may be attributed to the high surface area of biochar, leading to an increase in exchange sites. The formation of organo-mineral complexes with biochar in the soil might contribute to the observed increase in CEC. Ulyett *et al.* (2014) reported a significant increase in CEC with the addition of biochar. Biochar application plays a vital role in enhancing soil fertility and improving soil quality by increasing soil pH, improving cation exchange capacity and enhancing nutrient retention in the soil (Chan *et al.*, 2007). The slight increase in CEC with FYM addition may be attributed to the decomposition of FYM in the soils, forming humus and humic substances, which contribute to the overall CEC. This finding aligns with the results obtained by Adeniyan *et al.* (2011).

Effect of Mulberry Stalk Biochar and FYM on Available Nutrient Status of Soil (Available Nitrogen, Phosphorus and Potassium) at Harvest of Mulberry

Available Nitrogen (kg ha^{-1})

The results pertaining to the status of available nitrogen in the soil in relation to different treatments are presented in Table 5. The effects of the different treatments have a significant impact on available nitrogen in soil. The soil available nitrogen was found higher under treatment when biochar was applied with the combination of FYM compared to the sole application of biochar. Higher available nitrogen being recorded in T_8 (313.82 kg ha^{-1}) and the next best treatments were soil application of biochar @ 7.5 t ha^{-1} + FYM @ 10 t ha^{-1} (306.86 kg ha^{-1}) and soil application of biochar @ 5 t ha^{-1} + FYM @ 10 t ha^{-1} (300.36 kg ha^{-1}) while the lower values were recorded in control (268.91 kg ha^{-1}) treatment. The application of biochar in combination with FYM showed significant variations in available nitrogen content.

The higher content of available nitrogen was observed in the treatments that received the combined application of biochar and FYM at all mulberry crop cuttings. This could be due to that biochar plays an essential role in a nutrient cycle thus affecting N retention in soil and also due to more release and additive effect of mineralization. Although biochar itself is not a direct source of nitrogen but it acts as a microhabitat for added N fertilizer (added fertilizer which was trapped inside the biochar pores) and makes it available at later stages of crop. Biochar also reduces leaching losses of N from the soil.

Biochar efficiently adsorbs ammonia (NH_3) and acts as a binder for ammonia in soil, therefore, has the potential to decrease ammonia volatilization from soil surfaces. Nitrogen retention could be improved as biochar provides a microhabitat with controlled release of nutrients to soil and also higher microbial consortium was attributed to the enhanced mineralization under favorable soil conditions. Stevenson (1994) reported that the microbial consortium helps in mineralization leading to the release of ammoniacal nitrogen throughout the crop growth and also reduces the leaching losses of nitrogen and strongly retained in the soil. The slow release of N from biochar resulted in an increased availability of N and less loss of nitrogen (Chan and Xu, 2009 and Steiner *et al.*, 2007). It might also be due to N immobilization and decreased loss of N by leaching in the presence of recalcitrant biochar materials (Rondon *et al.*, 2007).

TABLE 5

Effect of mulberry stalk biochar and FYM on major nutrient status of soil at harvest of mulberry

Treatments	Avail. N	Avail. P_2O_5	Avail. K_2O
		(kg ha^{-1})	
T_1: Control (N:P_2O_5:K_2O 350:140:140 kg ha^{-1})	268.91	36.89	211.54
T_2: POP (FYM (25 t ha^{-1}) + N:P_2O_5:K_2O 350:140:140 kg ha^{-1}))	292.46	43.98	228.40
T_3: Soil application of biochar @ 5 t ha^{-1}	276.49	39.35	217.18
T_4: Soil application of biochar @ 7.5 t ha^{-1}	279.34	42.38	221.23
T_5: Soil application of biochar @ 10 t ha^{-1}	283.72	43.75	225.80
T_6: Soil application of biochar @ 5 t ha^{-1} + FYM@ 10 t ha^{-1}	300.36	47.45	232.65
T_7: Soil application of biochar @ 7.5 t ha^{-1} + FYM @ 10 t ha^{-1}	306.86	49.27	236.83
T_8: Soil application of biochar @ 10 t ha^{-1} +FYM @ 10 t ha^{-1}	313.82	50.41	240.96
S.Em ±	7.51	1.15	5.22
CD @ 5 %	22.78	3.49	15.83

Biochar application can reduce nutrient leaching from soil resulting an increase in fertilizer use efficiency. Various other studies indicated that the addition of biochar recorded higher available nitrogen, phosphorus and potassium in soil by Widowati *et al.* (2012) and Widowati and Asnah (2014). Venkatesh *et al.* (2018) observed application of pigeon pea biochar increased the soil available nitrogen by 26 per cent over the initial soil available nitrogen (109.4 kg ha^{-1}) as application of pigeon pea biochar improved the soil physical properties which might have altered the inorganic nitrogen pool and due to its higher surface area reduced the leaching losses

High contents of nitrogen in soils treated with biochar could be due to the improvement of chemically active surfaces in the soil system. Asai *et al.* (2009) reported that the application of biochar modifies the physical environment of soil and the dynamics of soil nutrients. Biochar improved the soil physical properties which might have altered the inorganic nitrogen pool. Sukartono *et al.* (2011) supported that an increase in nitrogen content as biochar minimises nutrient leaching, especially ammonical nitrogen. Biochar increases nitrogen use efficiency by improving the nitrification process (Zwieten *et al.*, 2010 and Ulyett *et al.*, 2014). Studies by Nelissen *et al.* (2012) also observed that an increase in nitrogen content by biochar addition due to an enhanced nitrification rate because biochar absorbs the potential inhibitors of nitrification such as monoterpenes and various polyphenolic compounds.

Shen *et al.* (2016) reported that biochar application enhanced soil nitrogen availability to the plant, since it acts as a soil conditioner, alters the soil chemical and microbial properties favourably, protecting nitrogen from losses and resulting in an increased availability.

Available Phosphorus (kg ha^{-1})

The application of different levels of biochar in combination with FYM significantly influenced the available phosphorus (Table 5). Among all the treatments T_8 which received soil application of biochar @ 10 t ha^{-1} + FYM @ 10 t ha^{-1} significantly recorded higher available phosphorus (50.41 kg ha^{-1}) followed by T_7 (49.27 kg ha^{-1}) and T_6 (47.45 kg ha^{-1}) treatment compared to POP (43.98 kg ha^{-1}) and were significantly superior over other treatments. Significantly, lower values of available phosphorus were found in the control (36.89 kg ha^{-1}).

The possible mechanisms for increased P_2O_5 availability in soil is due to, biochar acts as a modifier of soil pH and ameliorator of P complexing metals (Al^{3+} & Fe^{3+}) and promoter of microbial activity. Uzoma *et al.* (2011) conducted an experiment on maize by application of cow manure biochar and reported an increase in P availability as a result of an increase in soil pH. The increase in pH values leads to an increase in the number of negative charges of soil colloids, leading to more anionic repulsion and reduction of sorption of phosphate anions leading to a greater quantity of free phosphorus in soil solution (Mukherjee *et al.*, 2011).

Opala *et al.* (2012) supported these results of a significant increase in available phosphorus with the addition of biochar by improved microbial activity and microbially mediated mineralization of soil phosphorus to available phosphorus form. Further, biochar application increases the soil available phosphorus due to the effect of biochar on soil reaction which increases the mobility of phosphate ions in the soil solution (Husien *et al.*, 2017).

The use of biochar and FYM can supply the soil with P and improve its availability by reducing sorption and leaching. Other studies have reported that biochar and compost amended Ferralsols resulted in lower leaching and higher P uptake by plants (Agegnehu *et al.*, 2015 and Lehmann *et al.*, 2003) inferring that organic amendments can provide a slow-release P pool, additional to conventional fertilizer, through mineralization reactions (Wang *et al.*, 2014). This input contributes to an increase in the soil available P and can be critical to alleviate the P limitation. Another common mechanism of biochar application to increase P availability is the liming effect that decreases P adsorption and facilitates P desorption from Al and Fe oxides.

Available Potassium (kg ha^{-1})

Available potassium in soil varied from 211.54 to 240.96 kg ha^{-1} with a higher value being recorded in the treatment T_8 (240.96 kg ha^{-1}) which received biochar @ 10 t ha^{-1} + FYM @ 10 t ha^{-1} and it was on par with the treatment T_7 (236.83 kg ha^{-1}) and T_6 (232.65 kg ha^{-1}) and found superior over other treatments (Table 5). Significantly lower potassium status was recorded (211.54 kg ha^{-1}) in T_1 treatment (control).

The increase in available potassium status was observed in the treatment which received the combined application of biochar and FYM. This might be due to the biochar itself having more amount of potassium content compared to other major nutrients, so the addition of ash rich biochar to soil increased the K content of the soil. The application of biochar increased the pH of the soil which intern react on strongly attached K on soil clay particles and released into the soil solution (Smider & Singh, 2014 and Manolikaki & Diamadopoulos, 2016). The increase in potassium of biochar applied soil was due to the presence of cation exchange sites on the surface of biochar (Sohi *et al.,* 2010). Bindu *et al.* (2016) noticed that the high cation exchange capacity of biochar represents its ability to attract electrostatically cations like K^+ could be the reason for the increased availability of potassium in soil. The carbonate and carboxylate functional groups of biochar are responsible for the retention of potassium along with other nutrients. The increase in the potassium content on conjunctive use of biochar along with FYM could be due to the direct supply of potassium from mineral sources and the increase in surface charge of soils on biochar addition which might hold positively charged ions and minimise the leaching losses (Sukartono *et al*., 2011).

Effect of Mulberry Stalk Biochar and FYM on Biological Properties of Soil (Urease, Dehydrogenase and Phosphatase Activity) at Harvest of Mulberry

Urease Activity (µg NH$^+$4-N g^{-1} Soil h^{-1})

The perusal data on urease activity influenced by the combined application of biochar and FYM is presented in Table 6 and Fig. 1. Urease activity significantly differed with different treatments. The lower urease activity was recorded in control and increased significantly due to the 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 (68.74 µg

TABLE 6

Effect of mulberry stalk biochar and FYM on biological properties of soil at harvest of mulberry

Treatments	Urease (µg NH4+-N g^{-1}soil h^{-1})	Dehydrogenase (µg TPF g^{-1} soil 24 h^{-1})	Phosphatase (µg PNP g^{-1} soil h^{-1})
T_1: Control (N:P_2O_5:K_2O 350:140:140 kg ha^{-1})	49.53	44.98	20.81
T_2: POP (FYM (25 t ha^{-1}) + N:P_2O_5:K_2O 350:140:140 kg ha^{-1}))	61.29	56.06	27.87
T_3: Soil application of biochar @ 5 t ha^{-1}	55.44	50.46	26.48
T_4: Soil application of biochar @ 7.5 t ha^{-1}	57.82	52.39	27.70
T_5: Soil application of biochar @ 10 t ha^{-1}	59.32	54.64	29.20
T_6: Soil application of biochar @ 5 t ha^{-1} + FYM@ 10 t ha^{-1}	62.50	56.35	29.72
T_7: Soil application of biochar @ 7.5 t ha^{-1} + FYM @ 10 t ha^{-1}	65.55	58.09	31.96
T_8: Soil application of biochar @ 10 t ha^{-1} +FYM @ 10 t ha^{-1}	68.74	60.73	34.07
S.Em ±	1.53	1.36	0.70
CD @ 5 %	4.65	4.12	2.11

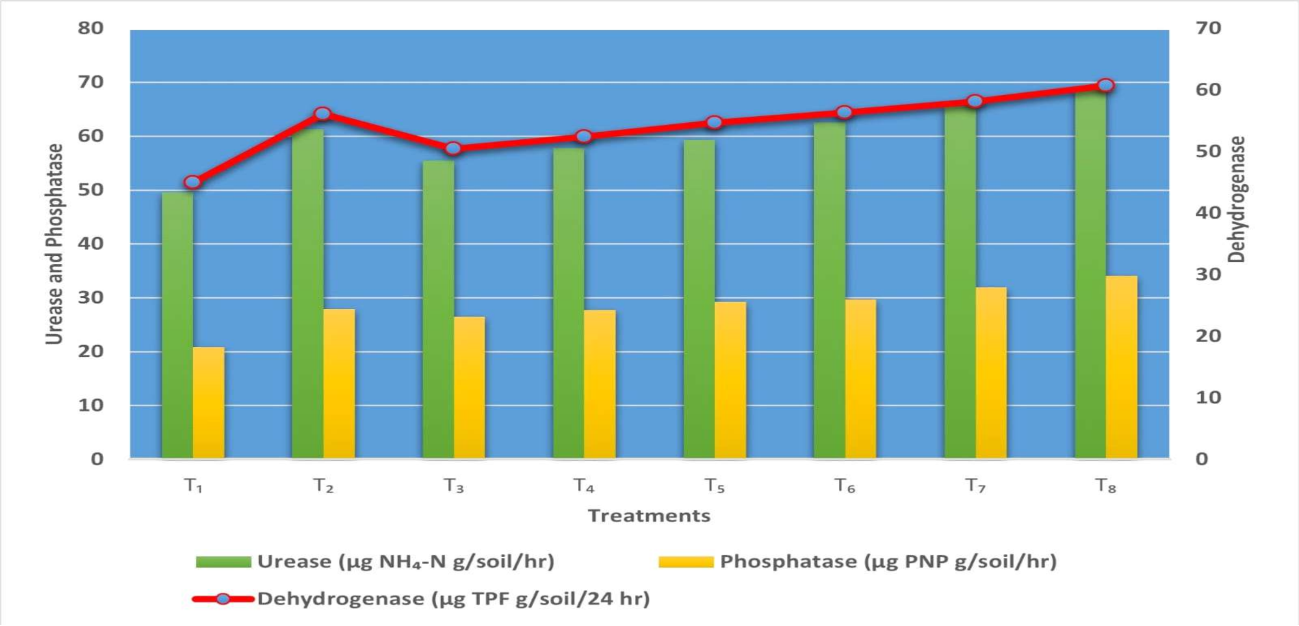

Fig. 1: Effect of mulberry stalk biochar and FYM on biological properties of soil at harvest of mulberry

NH^{+}4-N g^{-1} soil h^{-1}) and it was on par with the treatment T$_7$ (65.55 μg NH^{+}4-N g^{-1} soil h^{-1}) and T$_6$ (62.50 μg NH^{+}4-N g^{-1} soil h^{-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 an increase in enzyme activity with the addition of organic carbon through FYM and biochar to the soil. The increase in organic carbon 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).

Dehydrogenase Activity (μg TPF g^{-1} Soil 24 h^{-1})

Application of FYM and different levels of biochar significantly influenced the dehydrogenase activity and the values ranged from 44.98 to 60.73 μg TPF g^{-1} soil 24 h^{-1} (Table 6 and Fig. 1). The data showed marked significant differences with respect to dehydrogenase activity and the highest dehydrogenase activity was being recorded in T$_8$ (60.73 μg TPF g^{-1} soil 24 h^{-1}) and the next best treatment were T$_7$ (58.09 μg TPF g^{-1} soil 24 h^{-1}) and T$_6$ (56.35 μg TPF g^{-1} soil 24 h^{-1}) while the lowest value was recorded in control (44.98 μg TPF g^{-1} soil 24 h^{-1}). The application of a higher dose of biochar along with FYM increased the dehydrogenase activity. This is mainly due to an increase in enzyme activity with the addition of organic carbon through FYM and the application of biochar to the soil. Because biochar has a 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) 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.

Phosphatase Activity (μg PNP g^{-1} Soil h^{-1})

The results pertaining to phosphatase activity in relation to different treatments is presented in Table 6 and Fig.1. The effects of the different treatments have a 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 the sole application of biochar. The highest phosphatase activity in soil (34.07 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 T7 (31.96 µg PNP g^{-1} soil h^{-1}) and T_6 (29.72 µg PNP g^{-1} soil h^{-1}), while the minimum phosphatase activity in soil (20.81 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 treatment T_1. The higher values of phosphatase enzyme activity are recorded with a higher rate of biochar application in combination with FYM. Marinara *et al.* (2006) also reported that higher soil organic carbon contents may potentially explain increased enzyme activities. It is also due to the fact that due to the addition of both biochar and FYM, there was a better root growth that contributed to higher phosphatase activity and it is well known that phosphatase is the main root originated. The increased pH values in the soil could also enhance the availability of nutrients and consequently increase soil microbial biomass (Atkinson *et al.*, 2010 and Warnock *et al.*, 2010). Activities of certain enzymes like alkaline phosphatase, aminopeptidase and N-acetyl glycosaminidase have been reported to increase due to biochar application (Bailey *et al.*, 2010).

The application of biochar has yielded substantial improvements in physical, chemical and biological properties of soil, distinguishing it from conventional treatments involving NPK and POP. Application of biochar @ 10 t ha^{-1} + FYM 10 t ha^{-1} has notably reduced soil bulk density while concurrently enhancing maximum water holding capacity (MWHC), aggregate stability, pH, electrical conductivity (EC), organic carbon (OC) and cation exchange capacity (CEC), available nitrogen, phosphorus and potassium. Furthermore, it increased enzymatic activities of urease, dehydrogenase and phosphatase followed by soil application of biochar @ 7.5 t ha^{-1} + FYM 10 t ha^{-1} and soil application of biochar @ 5 t ha^{-1} + FYM 10 t ha^{-1}. Control treatment with no biochar and FYM application recorded significantly lower soil physical, chemical and biological properties.

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