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Effect of Levels of Coconut Shell Biochar and Farm Yard Manure on Soil Properties under Upland Rice Cultivation

B. R. Arunkumar[1*], G. N. Thippeshappa[1] and Basavarajappa H. Bhogi[2]

[1]Department of Soil Science and Agricultural Chemistry, University of Agricultural and Horticultural Sciences, Navile, Shivamogga, Karnataka, India.
[2]Department of Agricultural Engineering, University of Agricultural and Horticultural Sciences, Navile, Shivamogga, Karnataka, India.

Authors' contributions

This work was carried out in collaboration among all authors. Author BRA performed the chemical analysis, designed the study and wrote the first draft of the manuscript. Authors GNT and BHB assisted in chemical analysis, data interpretation and draft correction. All authors read and approved the final manuscript.

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ABSTRACT

An field experiment were conducted at ZAHRS, UAHS, Shivamogga, during summer 2018 to know the effect of biochar and Farm Yard Manure (FYM) on soil properties. The experiment was planned in Randomized Complete Block Design (RCBD) with 16 treatments consisting of four levels of biochar at 2, 4, 6 and 8 t ha^{-1} and two levels of FYM at 5 and 10 t ha^{-1} which were applied alone and in combinations. The recommended dose of fertilizer was applied commonly to all the treatments with three replications. The result revealed that combined application of 8 t ha^{-1} biochar + 10 t ha^{-1} FYM with Recommended Dose of Fertilizer (RDF) (100:50:50 kg ha^{-1}) to soil significantly decreased the soil Bulk density (1.30%) and Permanent wilting point (2.13%) and increased the soil porosity (50.94%), Maximum water holding capacity (37.30%), Field capacity (19.71%) and water stable aggregates (67.40%) as compared to initial soil properties of experimental site. Significantly increased the soil pH (initial acidic (5.88) to neutral at harvest (7.05)), Electrical Conductivity (EC)

**Corresponding author: E-mail: arunybr011@gmail.com;*

(0.37 dS m^{-1}), Cation Exchange Capacity (CEC) (17.86 [cmol (p^+ kg^{-1})]), available Nitrogen (340.24 kg ha^{-1}), Phosphorus (79.54 kg ha^{-1}), Potassium (252.46 kg ha^{-1}) and Sulfur (13.55 mg kg^{-1}). Soil Diethylene triamine penta acetic acid (DTPA) extractable micronutrients, soil enzymes and microbial biomass compared to absolute control and RDF alone treatments.

Keywords: Coconut shell biochar; soil pH; exchangeable calcium; phosphorus; soil enzymes; microbial biomass.

1. INTRODUCTION

Biochar produced from varied technological methods of pyrolysis can convert agriculture crop residues like coconut shells, arecanut husks, maize cob, cereal-pulse crop husks, grasses, forestry products, animal and poultry manures to biochar. Pyrolysis is the heating of biomass in a limited oxygen condition or complete in the absence of oxygen, causing the release of volatile carbon structures, hydrogen (H), methane (CH_4) and carbon monoxide (CO). The volatile carbon structures (alcohols, oils, tars, acids, *etc*.) can be re-condensed as bio-oil. The biochar that remains consists mainly C, and contains O, H, N and ash [calcium (Ca), potassium (K), *etc.,*]. Biochars with large amounts of carbon in poly-condensed aromatic structures are obtained by pyrolyzing organic feed stocks at high temperatures (400 to 700°C), but also have fewer ion exchange functional groups due to dehydration and decarboxylation, potentially limiting its usefulness in retaining soil nutrients.

On the other hand, biochars produced at lower temperatures (250 to 400°C) have higher yield recoveries and contain more C=O and CH functional groups that can serve as nutrient exchange sites after oxidation. Moreover, biochars produced at lower pyrolysis temperatures have more diversified organic character, including aliphatic and cellulose type structures. These may be good substrates for mineralization by bacteria and fungi, which have an integral role in nutrient turnover processes and aggregate formation. Biomass selection also has a significant influence on biochar surface properties and its elemental composition.

Biochar is a fine grained, highly porous charcoal substance that is distinguished from other charcoals in its intended use as a soil amendment. The particular heat treatment of organic biomass used to produce biochar contributes to its large surface area and its characteristic ability to persist in soils with very little biological decomposition [1]. While raw organic materials supply nutrients to plants and soil microorganisms. Biochar serves as a catalyst that enhances plant uptake of nutrients and water. Compared to other soil amendments, the high surface area and porosity of biochar makes it to adsorb or retain nutrients and hold moisture and in addition to this labile fraction of C in biochar provides C and energy to heterotrophic beneficial microorganisms to flourish and the ash fraction may supply some of the mineral nutrient requirements for crops [2,3].

Addition of biochar to soils has attracted widespread attention as a method to sequester carbon in the soil. Increased soil carbon sequestration can improve soil quality because of the vital role that carbon plays in chemical, biological and physical soil processes and many interfacial interactions.

Biochar application to soil may thus improve the physical properties of soil because of retardation of native stable organic matter decomposition. It persists for a longer time in soil. Therefore, it is indeed to study the residual effect of biochar on growth and yield of succeeding crop. The studies on effects of biochar application on soil properties especially in aerobic soils or its potentiality as a nutrient source are very scanty and it deserves detailed investigation.

2. MATERIALS AND METHODS

A field experiment was conducted at ZAHRS, College of Agriculture, UAHS, Shivamogga, during summer 2018 to know the effect of biochar on soil properties under aerobic rice cultivation. Initial characterization of soil experimental site indicated that soil had a Bulk density of 1.73 Mg cm^{-3}, maximum water holding capacity of 24.58 per cent, field capacity of 11.80 per cent and pH of 5.88, EC of 0.22 dSm^{-1} with the CEC of 14.43 cmol (p+) kg^{-1}. Further, the soil was low in available nitrogen (213.35 kg ha^{-1}), high in available phosphorus status (58.17 kg ha^{-1}) and medium in available potassium status (157.63 kg ha^{-1}). The exchangeable Ca and Mg were 2.85 and 1.74 (cmol (p^+) kg^{-1}), Available sulphur was 11.59 ppm and all the DTPA extractable micronutrients were above the critical limits (Fe- 12.18, Mn-2.58, Zn-2.18 and Cu-1.13 ppm). The soil belongs to the taxonomic class of *Typichaplustalf* with sandy loam texture. The experiment was planned with 16 treatments consisting of four levels of CS- biochar (Coconut Shell biochar) at 2, 4, 6 and 8 t ha^{-1} and two levels of FYM at 5 and 10 t ha^{-1} which were applied alone, and in combinations. The recommended dose of fertilizer (RDF) was applied commonly to all the treatments. The treatments were imposed in Randomized Complete Block Design (RCBD) with three replications for each treatment. The aerobic rice (MAS 946-1) was taken up as a testing crop. Soil samples were collected from respective treatments at panicle initiation and harvest of crop and was analyzed for different soil properties by adopting standard procedures. Properties of biochar and FYM used in experiment were given in Table 1.

2.1 Statistical Analysis

The experimental data obtained were subjected to statistical analysis adopting Fisher's method of analysis of variance as out lined by [4]. The level of significance used in the F test was at 5 per cent. Critical difference (CD) values are given for the data at 5 per cent level of significance, wherever the F test was significant.

3. RESULTS AND DISCUSSION

3.1 Effect of Levels of Biochar on Soil Physical Properties under Aerobic Rice Cultivation

Results pertaining to soil physical properties *viz.,* bulk density (BD), maximum water holding capacity (MWHC), field capacity (FC), permanent wilting point (PWP), available water and water stable aggregates as influenced by levels of coconut shell biochar (CS-biochar) at harvest stage under aerobic rice cultivation is presented in Table 2.

The physical properties of soil *viz.,* bulk density, porosity, maximum water holding capacity, field capacity moisture, permanent wilting point moisture, available water and aggregate stability were significantly influenced by CS-biochar application (Table 2). Among the treatments, the combined application of CS-biochar and FYM has recorded lower bulk density, lower permanent wilting point moisture, and higher porosity, maximum water holding capacity, field capacity moisture, higher soil available water and aggregate stability over the rest of the treatments. This could be due to application of organic carbon in the form of FYM and CS-biochar. Biochar and FYM addition to soil decreased the bulk density of the soil and increased the total porosity and it increase available water content and water holding capacity of soil by enhancing soil porosity and aggregate formation in sandy or loamy soil. FYM and CS-biochar act as cementing materials in forming stable soil aggregates. It has been suggested that the porous structure of biochar can influence its impact on soil porosity, bulk density, water holding capacity and adsorption capacity [5,6]. Moreover, biochar particles are known for having more porosity to retain water due to their spherical shape and deformability [7].

3.2 Effect of Levels of Biochar on Soil Physico-Chemical Properties and Nutrient Status at Panicle Initiation Stage and Harvest of Aerobic Rice

The results on the effect of levels of CS-biochar with FYM on physico-chemical properties like pH, electrical conductivity (EC), CEC and soil chemical properties like soil primary, secondary and micronutrients status at panicle initiation and harvest stage of aerobic rice crop is presented in Tables 3 to 6.

3.2.1 Soil pH, Electrical Conductivity (EC) and Cation Exchange Capacity (CEC)

The results recorded in relation to the effect of levels of CS-biochar on pH, EC and CEC of soil at panicle initiation and harvest stage of aerobic rice crop is presented in Table 3.

Application of increased levels of CS-biochar, FYM and their combination increased the pH of acid soil near to neutral at both panicle initiation and at harvest stage over absolute control (T_1). However, increase in pH of soil was found non-significant at panicle initiation stage due to CS-biochar and FYM application.

At harvest stage, the treatments which received increased levels of CS-biochar with FYM combination and CS-biochar and FYM alone increased the soil pH over absolute control and

Table 1. Physical and chemical properties of biochar and FYM

Sl. No.	Physico-chemical properties	Biochar	FYM
1.	Bulk density (Mg m^{-3})	0.51	0.82
2.	MWHC (%)	63.00	48.00
3.	FC (%)	42.00	20.14
4.	pH (1: 5)	8.78	7.70
5.	EC (dSm^{-1}) (1: 5)	1.86	0.46
6.	CEC (cmol (p^+) kg^{-1})	26.25	17.51
	Chemical properties		
7.	Carbon (%)	48.37	10.43
8.	Nitrogen (%)	0.42	0.57
9.	C : N ratio	115.17	18.29
10.	Phosphorus (%)	0.17	0.22
11.	Potassium (%)	1.26	0.54
12.	Calcium (%)	2.30	0.51
13.	Magnesium (%)	0.48	0.38
14.	Sulphur (%)	0.10	0.05
15.	Iron (mg kg^{-1})	257.27	98.00
16.	Manganese (mg kg^{-1})	343.80	77.00
17.	Zinc (mg kg^{-1})	27.40	181.16
18.	Copper (mg kg^{-1})	34.10	24.28

RDF alone. However, significantly higher soil pH value of 7.05 were recorded in the treatment, T_{16} (8 t ha^{-1} CS-biochar + 10 t ha^{-1} FYM + RDF) and which was on par with all other treatments except T_4 (6.10), T_3 (6.01), T_2 (5.73) and T_1 (5.87) treatments.

The observed changes in pH of soil applied with CS-biochar could be ascribed to the release of alkaline compounds from biochar, which neutralized the soil acidity and thus increased the soil pH to some extent. 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 and thus alleviate soil pH. As CS-biochar contain significant quantity of Ca, it can replace the monomeric Al species from soil exchange complex in acidic soil. Accompanying this reaction, there could be increase in soil solution pH caused by the depletion of the readily hydrolysable monomeric Al and the formation of the more neutral $[Al(OH)_3]^0$ species [8]. The findings of present study is in line with several authors *viz.,* [9,10,11] who recorded increase in soil pH by applying different kinds of biochar to soil. Application of wood bark biochar at 37 t ha^{-1} increased the pH by 1.0 to 1.5 units [11].

Application of increased levels of CS-biochar, FYM and their combination increased the EC of soil at both panicle initiation and harvest stage of crop over absolute control (T_1) (Table 3). However, increase in EC of soil was found to be non-significant at both panicle initiation and harvest stage of crop. Increased in EC of soil was noticed at both panicle initiation and harvest stage as the levels of biochar and FYM increased. However, the higher EC value of soil recorded to be 0.33 and 0.37 dS m^{-1} in the treatment which received 8 t ha^{-1} CS-biochar + 10 t ha^{-1} FYM with RDF (T_{16}) at panicle initiation and harvest stage of crop, respectively.

Application of different levels of CS-biochar had influence on electrical conductivity. CS-biochar in combination with FYM and fertilizer to soil showed difference with respect to soil electrical conductivity. However, the treatment (T_{16}) received CS-biochar 8 t ha^{-1} + FYM 10 t ha^{-1} with RDF showed the maximum (0.37 dS m^{-1}) electrical conductivity and minimum value (0.20 dS m^{-1}) of EC was in the absolute control treatment (T_1) at harvest of crop. This may be due to the presence of salt content and exchangeable cations in the coconut shell biochar which can increase the EC of treated plots compared to untreated plot. [12] attributed the increase in EC of soil due to application of biochar are generally dominated by carbonates of alkali, amounts of silica, phosphates, and small amounts of organic and inorganic N. Similar results were also reported by [13]. Significant increase in EC with varied levels of biochar application was often reported in the literature by [14-17].

Table 2. Effect of levels of biochar on soil physical properties at harvest under aerobic rice cultivation

Treatments	Bulk density ($Mg\ M^{-3}$)	Porosity	MWHC	FC	PWP	Available water content	Water stable aggregates
		%					
T1: Absolute Control	1.60	39.62	23.92	10.87	4.68	6.19	27.10
T2: 100:50:50 NPK kg ha^{-1} (Only RDF)	1.56	41.13	26.73	11.72	4.37	7.35	33.40
T3: FYM@ 5 t ha^{-1}	1.47	44.53	31.45	16.82	3.84	12.98	58.40
T4: FYM@ 10 t ha^{-1} (POP)	1.44	45.66	31.43	17.66	3.76	13.90	60.60
T5: CS - Biochar@ 2 t ha^{-1}	1.49	43.77	28.50	15.92	3.73	12.19	56.10
T6: CS - Biochar@ 4 t ha^{-1}	1.46	44.91	30.64	16.30	3.61	12.69	58.61
T7: CS - Biochar@ 6 t ha^{-1}	1.45	45.28	31.90	16.88	3.53	13.35	61.60
T8: CS - Biochar@ 8 t ha^{-1}	1.43	46.04	33.10	18.03	2.44	15.59	62.00
T9: CS - Biochar @2 t ha^{-1} + FYM @ 5 t ha^{-1}	1.45	45.28	30.20	17.21	2.68	14.53	62.10
T10: CS - Biochar@ 4 t ha^{-1} + FYM@ 5 t ha^{-1}	1.41	46.79	33.80	17.41	2.64	14.77	64.40
T11: CS - Biochar@ 6 t ha^{-1} + FYM@ 5 t ha^{-1}	1.39	47.55	35.10	17.67	2.58	15.09	65.20
T12: CS - Biochar@ 8 t ha^{-1} + FYM@ 5 t ha^{-1}	1.37	48.30	35.60	18.80	2.36	16.44	65.90
T13: CS - Biochar@ 2 t ha^{-1} + FYM@ 10 t ha^{-1}	1.41	46.79	32.50	18.67	2.33	16.34	65.80
T14: CS - Biochar@ 4 t ha^{-1} + FYM@ 10 t ha^{-1}	1.38	47.92	34.30	19.19	2.26	16.93	66.70
T15: CS - Biochar@ 6 t ha^{-1} + FYM@ 10 t ha^{-1}	1.34	49.43	35.70	19.57	2.18	17.39	67.10
T16: CS - Biochar@ 8 t ha^{-1} + FYM@ 10 t ha^{-1}	1.30	50.94	37.30	19.71	2.13	17.58	67.40
S.Em±	0.02	0.77	0.49	0.20	0.05	0.23	1.52
C.D. (p=0.05)	0.06	2.04	1.41	0.61	0.16	0.65	4.37

Table 3. Effect of levels of biochar on soil physico-chemical properties at different crop growth stages under aerobic rice cultivation

Treatments	pH (1:2.5)		EC (1:2) (dS m^{-1})		CEC (cmol (P^+) kg^{-1})	
	Panicle initiation	Harvest	Panicle initiation	Harvest	Panicle initiation	Harvest
T1: Absolute Control	5.62	5.87	0.19	0.20	13.01	13.49
T2: 100:50:50 NPK kg ha^{-1} (Only RDF)	5.68	5.73	0.20	0.23	12.81	14.16
T3: FYM@ 5 t ha^{-1}	6.13	6.01	0.23	0.21	15.83	15.72
T4: FYM@ 10 t ha^{-1} (POP)	6.18	6.10	0.24	0.24	15.90	15.80
T5: CS - Biochar@ 2 t ha^{-1}	6.21	6.38	0.27	0.29	15.64	16.43
T6: CS - Biochar@ 4 t ha^{-1}	6.26	6.42	0.28	0.29	15.64	16.49
T7: CS - Biochar@ 6 t ha^{-1}	6.41	6.57	0.27	0.30	15.69	16.91
T8: CS - Biochar@ 8 t ha^{-1}	6.53	6.59	0.30	0.31	15.82	17.53
T9: CS - Biochar @2 t ha^{-1} + FYM @ 5 t ha^{-1}	6.83	6.89	0.27	0.29	17.10	17.12
T10: CS - Biochar@ 4 t ha^{-1} + FYM@ 5 t ha^{-1}	6.88	6.93	0.29	0.30	17.16	17.38
T11: CS - Biochar@ 6 t ha^{-1} + FYM@ 5 t ha^{-1}	6.90	6.93	0.31	0.33	17.20	17.32
T12: CS - Biochar@ 8 t ha^{-1} + FYM@ 5 t ha^{-1}	6.98	7.01	0.32	0.36	17.29	17.71
T13: CS - Biochar@ 2 t ha^{-1} + FYM@ 10 t ha^{-1}	6.83	6.87	0.29	0.30	17.10	17.40
T14: CS - Biochar@ 4 t ha^{-1} + FYM@ 10 t ha^{-1}	6.84	6.91	0.31	0.33	17.13	17.26
T15: CS - Biochar@ 6 t ha^{-1} + FYM@ 10 t ha^{-1}	6.89	6.97	0.31	0.36	17.28	17.31
T16: CS - Biochar@ 8 t ha^{-1} + FYM@ 10 t ha^{-1}	6.98	7.05	0.33	0.37	17.38	17.86
S.Em±	0.43	0.23	0.08	0.02	0.59	0.64
C.D. (p=0.05)	NS	0.68	NS	NS	1.70	1.84

The CEC of soil significantly increased both at panicle initiation and harvest stage in all treatments due to addition of levels of CS-biochar, FYM and their combinations over RDF alone (T_2) and absolute control (T_1). However, application of increased levels of CS-biochar (2 to 8 t ha^{-1}) and FYM (5 to 10 t ha^{-1}) and their combination increased the CEC of soil significantly at both panicle initiation and harvest stages of crop. Slightly higher values of CEC in soil was recorded at harvest stage than at panicle initiation stage and higher values of CEC was registered due to addition of higher dose of CS-biochar @ 8 t ha^{-1} and 10 t ha^{-1} FYM with RDF (T_{16}) which recorded 17.38 cmol (p^+) kg^{-1} and 17.86 cmol (p^+) kg^{-1} followed by all other treatments except absolute control and RDF alone both at panicle initiation and at harvest stage of crop, respectively.

Application of different levels of CS-biochar had significant influence on cation exchange capacity (CEC) of soil (Table 3). CS-biochar in combination with FYM and fertilizer to soil showed significant difference with respect to soil cation exchange capacity (CEC) at both panicle initiation and harvest stage. However, the treatments received CS-biochar @ 8 t ha^{-1} + FYM 10 t ha^{-1} with RDF showed the maximum CEC (17.86 cmol (p+) kg-1) CEC and minimum CEC value (13.49 cmol (p+) kg-1) due to treatment without CS-biochar and FYM at harvest of crop. This may be attributed to the higher surface area and acidic functional groups present on biochar surfaces which contributed to soil CEC [18]. Similarly, [13] also reported the capacity of biochar to increase in soil CEC could be because of high surface area and porous nature of biochar. It also has been suggested that the porous structure of biochar can influence its impact on soil cation adsorption capacity [19], [5] and [20].

3.2.2 Available primary nutrients (NPK) status in soil

The results pertaining to the effect of levels of CS-biochar and FYM and their combination on available N, P and K status of soil at panicle initiation and harvest of aerobic rice are presented in Table 4.

A significant increase and higher available nitrogen status in soil was noticed at panicle initiation stage due to combined application of CS-biochar and FYM at different levels with RDF over the absolute control, T_1 (227.84 kg ha^{-1}). However, among the treatments, the treatment T_{16} with CS-biochar 8 t ha^{-1} + FYM 10 t ha^{-1} + RDF recorded significantly higher available N (372.62 kg ha^{-1}) status followed by T_{15} (CS-biochar 6 t ha^{-1} + FYM 10 t ha^{-1} + RDF) which registered 361.64 kg ha^{-1} in soil at panicle initiation stage of aerobic rice crop. Even at harvest stage of crop the same trend was noticed in respect of available N status in soil. Here also the treatment, T_{16} (CS-biochar 8 t ha^{-1} + FYM 10 t ha^{-1} + RDF) recorded significantly higher value (340.24 kg ha^{-1}) followed by T_{15} (CS-biochar6 t ha^{-1} + FYM 10 t ha^{-1} + RDF) which recorded 313.98 kg ha^{-1} compared to all other treatments which were found to be higher than the initial soil available N (213.35 kg ha^{-1}) content.

The available nitrogen status of soil increased with the increased levels of CS-biochar and FYM applied in combination compared to alone application of CS-biochar and FYM at both panicle initiation and harvest. This is might be due to the fact that addition of CS-biochar and FYM in combined contributed available nitrogen to the soil due mineralization of FYM and biochar. Significantly higher value of available nitrogen 372.62 and 340.24 kg ha^{-1}, content of soil at panicle initiation and harvest stage, respectively was recorded with the application of CS-biochar @ 8 t ha^{-1} + RDF + FYM 10 t ha^{-1} (T_{16}). Similar findings were reported by [2] and [21]. [22] reported that biochar alters the N dynamics in soil. The availability and rate of mineralization of organic N found in biochar application to soil provides an indication of the ability of biochar as a slow release N fertilizer [23] and [24].

Biochar application can reduce nutrient leaching from soil with resulting increase in fertilizer use efficiency [25,8,26] and [27]. Increased retention of N with biochar addition was also observed earlier [8].

A significant increase in available P_2O_5 status of soil was noticed in both panicle initiation and harvest stage of crop due to the combined addition of increased levels of biochar and FYM with RDF over RDF alone and absolute control treatments (Table 4). The treatment which received CS-biochar @ 8 t $ha^{-1}$and FYM @ 10 t ha^{-1} with RDF (T_{16}) resulted in significant increase in the available P_2O_5 (87.23 kg ha^{-1}) followed by CS-biochar @ 6 t $ha^{-1}$and FYM @ 10 t ha^{-1} with RDF (T_{15}) which recorded 84.30 kg ha^{-1} of available P_2O_5 in soil compared to all other treatments at panicle initiation stage of aerobic rice. The same trend was noticed even at harvest stage of crop in respect of available status in soil. Significantly higher status of 79.54 kg ha^{-1} was registered with treatment, T_{16} (CS-biochar 8 t ha^{-1} biochar and 10 t ha^{-1} FYM + RDF) at harvest stage compared to all other treatments. However, the lowest available P_2O_5 content of 32.61 and 32.30 kg ha^{-1} was recorded in absolute control (T_1) at both panicle initiation and harvest stage, respectively.

The phosphorous status in soil increased with the increased levels of CS-biochar at both panicle initiation and at harvest stage. This may be due to the high concentrations of available P found in the biochar. [28,29] and [17] also reported the increase in available phosphorus in soil after the application of biochar. The possible mechanism for increased P_2O_5 availability with biochar application in soil can be attributed to presence of soluble and exchangeable phosphate in biochar, modifier of soil pH and ameliorator of P complexing metals (Al^{3+}, Fe^{3+}), promoter of microbial activity and hastening P mineralization. Such increase in available P_2O_5 content with biochar addition was also reported by [10] and [30]. Similar findings also reported, by [31] increase in soil P may be due to high content of P present in fresh biochar. Increase in soil pH may also reduce Al and Fe activity which could also contribute to higher soil P availability.

Like available nitrogen status, the available K_2O status in soil significantly increased in all the treatments due to the combined addition of levels of biochar and FYM at panicle initiation and harvest stage over absolute control (T_3) and RDF alone (T_2) (Table 4). Further, at given levels of FYM, with increased levels of biochar (2 to 8 kg ha^{-1}) application, a significant increase in available K status in soil was observed over individual application biochar. However, maximum to the extent of 287.67 and 252.46 kg ha^{-1}available K content in soil was noticed in treatment T_{16} (8 t ha^{-1} CS-biochar and 10 t ha^{-1} FYM + RDF) followed by T_{15} (6 t ha^{-1} CS-biochar and 10 t ha^{-1} FYM + RDF) which registered 275.85 and 236.90 kg ha^{-1} available K at both panicle initiation and harvest stage of crop, respectively. The lowest available K of 98.47 and 117.28 kg ha^{-1} was noticed in absolute control at both panicle initiation and harvest stage of crop, respectively.

The increased levels of CS-biochar increased the potassium status in soil at both panicle initiation and at post harvested soil which may be due to the high concentration of K found in the biochar [9]. The immediate beneficial effects of biochar additions on nutrient availability are largely due to higher potassium [21]. The biochar contained high ash and itself has more amount of potassium content compared to other major nutrients, so by the application of ash rich biochar to soils increased the potassium content significantly. Increased K availability by biochar application has also been reported by [32] which might be from the considerable amounts of K that were added along with the biochar from which it is readily leached.

3.2.3 Secondary nutrient (Ca, Mg and S) status in soil

The results obtained in relation to the effect of levels of CS-biochar and FYM with their combination on exchangeable and available secondary nutrients status in soil at panicle initiation and harvest stage of aerobic rice crop are presented in Table 5.

Exchangeable bases such as Ca and Mg content in soil varied significantly with application of varied levels of CS-biochar at both panicle initiation and at harvest stage due its high cation exchange capacity. The increased levels of biochar increased the calcium and magnesium content in panicle initiation and post harvested soil which may be due to the higher concentration of Ca, Mg and exchangeable bases in biochar. This might be due to high porosity and surface/volume ratio and can improved Ca and Mg availability [9,11].

Increase in exchangeable bases in soil at different intervals can be attributed to release of basic cations from CS-biochar. During pyrolysis, biomass acids are converted into bio- oil and alkalinity is inherited by solid biochar [10]. Most of the Ca, Mg, K, P, and plant micronutrients in feedstock are partitioned into the biochar ash fraction during pyrolysis. Ash in biochar rapidly releases free bases such as Ca, Mg and K to the soil solution thereby not only increases soil pH but also exchangeable bases. Such observations were also noticed by [21,17].

With regard to available S status in soil, with increased in levels of CS-biochar with FYM available S status in soil increased significantly at both panicle initiation and harvest stage of crop over absolute control and RDF alone (Table 5). At panicle initiation stage highest value of available S (13.08 mg kg^{-1}) in soil recorded by treatment, T_{16} (8 t ha^{-1} CS- biochar and 10 t ha^{-1} FYM + RDF) followed by T_{15} (6 t ha^{-1} CS-biochar and 10 t ha^{-1} FYM + RDF) which recorded 12.68 mg kg^{-1} which was on par with the treatment, which received 4 t ha^{-1} CS-biochar + 10 t ha^{-1}

FYM with RDF (12.14 mg kg^{-1}) (T_{14}). Lowest available S 8.61 kg ha^{-1} was noticed in T_1 treatment.

A similar trend was noticed even at harvest stage. Where, T_{16} (8 t ha^{-1} CS-biochar and 10 t ha^{-1} FYM + RDF) recorded significantly higher value of available S (13.55 mg kg^{-1}) followed by T_{15} (6 t ha^{-1} CS-biochar and 10 t ha^{-1} FYM + RDF) which registered 13.14 mg kg^{-1} which was on par with the treatment, which received 4 t ha^{-1} CS-biochar + 10 t ha^{-1} FYM with RDF (12.32 mg kg^{-1}) (T_{14}). Lowest available S content 7.34 mg kg^{-1} was noticed in T_1 treatment. Further, like Ca and Mg the available S status also increased in soil at harvest over panicle initiation stage.

Sulphur content in soil varied significantly with application of different levels of CS-biochar at panicle initiation and harvest of aerobic rice crop. This may be due the contribution of available sulphur to soil after the mineralization of organic sulphur in biochar and also due to addition of zinc sulphate and application of FYM. The results suggest that biochar also improves the bioavailability of sulphur; which mainly depends on mineralization of organic forms of sulphur to cycle through soils [33].

3.2.4 DTPA extractable micronutrients status in soil

The data pertaining to the DTPA extractable micronutrients like iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) status in soil at panicle initiation and harvest stage of aerobic rice as influenced by CS-biochar are presented in Table 6.

It was noticed that micronutrient status of soil increased with increased levels of biochar and FYM with their different combination over no CS-biochar or FYM application treatments. However, application of levels of CS-biochar alone decreased the micronutrients contents of soil over combined application of CS-biochar and FYM. Slightly higher status of micronutrient status in soil was recorded at harvest stage than at panicle initiation stage.

Application of biochar alone recorded lower status of micronutrients in soil which might be due to the adsorption, possible immobilization and precipitation. As pH of soil and micronutrients availability was negatively correlated, immobilization and precipitation of micronutrient occurs in soil. The decreased trend of metal content with different rate of biochar application was likely a function of the increase in total amount of active sites.

Although there was an increase in micronutrients content in the soil with CS-biochar application no definite pattern was obtained with application rate in this study at panicle initiation stage as compared to harvest of crop. This may be due to the mineralization of micronutrients from organic matter and the release of micronutrients during decomposition of organic manures. Increase in the content of micronutrients at harvest of crop might be due to higher availability of the plant nutrients from the soil nutrient reservoir and additional quantity of nutrients supplied through farm yard manure [34].

The significant increase in copper content of soil by application of biochar at both panicle initiation and at harvest could be due to increase the soluble organic carbon; thereby resulting in the mobilization of Cu. Cu is strongly chelated by organic carbon and is less subjected to adsorption process. [35] also reported dependence of Cu content on soluble C and pH.

There was no definite trend in micronutrient content by the application of different levels of CS-biochar alone in low pH soil. The variation in micronutrient content in soil with the application of CS-biochar can be attributed to its physical and chemical properties. Biochar by virtue of its high surface area, high metal affinity, higher nutrient retention capacity, presence of acidic and basic functional groups and ability to alkalize soil might result in immobilization and precipitation of micronutrients in soil. Such of these mechanisms of metal immobilization due to biochar application were also reported by [36,37].

Overall, soil nutrients availability was increased in the treatments received CS-biochar and FYM in combination as compared to individual application of different levels of biochar and FYM with RDF. The availability of nutrients in the biochar added soil may be related to the large surface area of biochar material providing adsorption sites. Moreover, the increase in the water.

holding capacity of biochar added soils may improve nutrient retention in the topsoil. Attachment of organic matter or minerals with sorbed nutrients (aggregation) to biochar may further increase nutrient retention. Several studies demonstrated that processing temperatures <500°C favour nutrient retention in biochar [23].

Table 4. Effect of levels of biochar on available primary nutrients status of soil at different crop growth stages under aerobic rice cultivation

Treatments	N (kg ha^{-1})		P_2O_5 (kg ha^{-1})		K_2O (kg ha^{-1})	
	Panicle initiation	Harvest	Panicle initiation	Harvest	Panicle initiation	Harvest
T1: Absolute Control	227.84	162.92	32.61	32.30	98.47	117 .28
T2: 100:50:50 NPK kg ha^{-1} (Only RDF)	268.04	226.35	52.43	45.96	121.68	125.31
T3: FYM@ 5 t ha^{-1}	284.43	247.82	66.33	55.17	255.04	156.54
T4: FYM@ 10 t ha^{-1} (POP)	292.66	254.47	71.56	60.51	258.27	159.83
T5: CS - Biochar@ 2 t ha^{-1}	261.49	261.57	57.47	40.35	241.11	145.42
T6: CS - Biochar@ 4 t ha^{-1}	273.49	270.54	61.27	50.22	243.31	171.16
T7: CS - Biochar@ 6 t ha^{-1}	282.53	274.03	62.83	51.47	254.24	192.33
T8: CS - Biochar@ 8 t ha^{-1}	283.31	281.85	65.31	54.73	255.03	215.71
T9: CS - Biochar @2 t ha^{-1} + FYM @ 5 t ha^{-1}	332.57	284.50	69.78	58.61	250.52	177.27
T10: CS - Biochar@ 4 t ha^{-1} + FYM@ 5 t ha^{-1}	344.87	289.58	75.42	69.05	251.72	200.36
T11: CS - Biochar@ 6 t ha^{-1} + FYM@ 5 t ha^{-1}	353.61	296.39	78.04	69.15	257.44	216.34
T12: CS - Biochar@ 8 t ha^{-1} + FYM@ 5 t ha^{-1}	360.39	308.57	83.21	72.74	260.74	232.65
T13: CS - Biochar@ 2 t ha^{-1} + FYM@ 10 t ha^{-1}	340.80	292.93	78.92	64.26	254.15	194.95
T14: CS - Biochar@ 4 t ha^{-1} + FYM@ 10 t ha^{-1}	352.80	298.08	83.38	63.87	257.15	230.22
T15: CS - Biochar@ 6 t ha^{-1} + FYM@ 10 t ha^{-1}	361.64	313.98	84.30	71.34	275.85	236.90
T16: CS - Biochar@ 8 t ha^{-1} + FYM@ 10 t ha^{-1}	372.62	340.24	87.23	79.54	287.67	252.46
S.Em±	4.15	9.53	1.26	2.37	10.05	6.77
C.D. (p=0.05)	11.98	27.53	3.62	6.85	29.04	19.56

Table 5. Effect of levels of biochar on secondary nutrients status of soil at different crop growth stages under aerobic rice cultivation

Treatments	Exch. Ca (cmol (P^+) kg^{-1})		Exch. Mg (cmol (P^+) kg^{-1})		s (mg kg^{-1})	
	Panicle initiation	Harvest	Panicle initiation	Harvest	Panicle initiation	Harvest
T1: Absolute Control	2.48	1.21	1.49	1.31	8.61	7.34
T2: 100:50:50 NPK kg ha^{-1} (Only RDF)	2.81	1.39	1.58	1.49	9.38	8.05
T3: FYM@ 5 t ha^{-1}	3.44	2.98	2.27	1.82	11.11	10.40
T4: FYM@ 10 t ha^{-1} (POP)	3.53	3.07	2.38	2.03	11.37	11.25
T5: CS - Biochar@ 2 t ha^{-1}	2.26	2.94	1.56	1.82	8.17	9.48
T6: CS - Biochar@ 4 t ha^{-1}	2.51	3.06	1.62	1.90	9.31	10.72
T7: CS - Biochar@ 6 t ha^{-1}	2.78	3.17	1.68	2.08	9.83	10.82
T8: CS - Biochar@ 8 t ha^{-1}	2.83	3.68	1.71	2.20	10.12	11.00
T9: CS - Biochar @2 t ha^{-1} + FYM @ 5 t ha^{-1}	2.53	3.32	1.75	2.16	11.20	11.64
T10: CS - Biochar@ 4 t ha^{-1} + FYM@ 5 t ha^{-1}	2.74	3.41	1.90	2.23	11.63	11.90
T11: CS - Biochar@ 6 t ha^{-1} + FYM@ 5 t ha^{-1}	2.90	3.63	1.97	2.26	11.71	12.06
T12: CS - Biochar@ 8 t ha^{-1} + FYM@ 5 t ha^{-1}	3.04	3.71	2.00	2.34	11.84	12.16
T13: CS - Biochar@ 2 t ha^{-1} + FYM@ 10 t ha^{-1}	2.91	3.56	1.99	2.24	11.68	12.10
T14: CS - Biochar@ 4 t ha^{-1} + FYM@ 10 t ha^{-1}	3.09	3.62	2.01	2.41	12.14	12.32
T15: CS - Biochar@ 6 t ha^{-1} + FYM@ 10 t ha^{-1}	3.28	3.80	2.15	2.69	12.68	13.14
T16: CS - Biochar@ 8 t ha^{-1} + FYM@ 10 t ha^{-1}	3.57	4.18	2.26	2.83	13.08	13.55
S.Em±	0.15	0.16	0.08	0.15	0.40	0.46
C.D. (p=0.05)	0.42	0.45	0.22	0.43	1.16	1.34

Table 6. Effect of levels of biochar on DTPA extractable micronutrients status of soil at different crop growth stages under aerobic rice cultivation

Treatments	Fe(mg kg^{-1})		Mn(mg kg^{-1})		Zn(mg kg^{-1})		Cu(mg kg^{-1})	
	Panicle initiation	Harvest	Panicle initiation	Harvest	Panicle initiation	Harvest	Panicle initiation	Harvest
T1: Absolute Control	11.61	9.34	2.41	1.89	1.66	1.22	1.31	1.07
T2: 100:50:50 NPK kg ha^{-1} (Only RDF)	11.98	9.65	2.33	1.84	1.70	1.36	1.43	1.10
T3: FYM@ 5 t ha^{-1}	13.40	12.28	2.10	2.70	1.55	2.17	1.60	2.02
T4: FYM@ 10 t ha^{-1} (POP)	13.69	12.72	2.32	2.94	1.63	2.23	1.73	2.13
T5: CS - Biochar@ 2 t ha^{-1}	13.37	13.06	1.24	2.07	1.42	2.10	1.51	1.81
T6: CS - Biochar@ 4 t ha^{-1}	13.18	13.23	1.38	2.21	1.78	2.21	1.68	1.87
T7: CS - Biochar@ 6 t ha^{-1}	13.63	13.61	1.61	2.61	1.78	2.21	1.70	2.00
T8: CS - Biochar@ 8 t ha^{-1}	13.79	13.90	1.78	2.69	1.91	2.48	1.75	2.12
T9: CS - Biochar @2 t ha^{-1} + FYM @ 5 t ha^{-1}	14.08	14.27	2.19	2.83	1.62	2.27	1.89	2.31
T10: CS - Biochar@ 4 t ha^{-1} + FYM@ 5 t ha^{-1}	14.12	14.31	2.43	2.98	1.79	2.40	2.08	2.38
T11: CS - Biochar@ 6 t ha^{-1} + FYM@ 5 t ha^{-1}	14.34	14.49	2.54	3.14	1.86	2.47	2.14	2.44
T12: CS - Biochar@ 8 t ha^{-1} + FYM@ 5 t ha^{-1}	14.37	14.91	2.71	3.27	2.06	2.70	2.31	2.52
T13: CS - Biochar@ 2 t ha^{-1} + FYM@ 10 t ha^{-1}	14.36	14.48	2.25	3.31	1.78	2.41	2.14	2.40
T14: CS - Biochar@ 4 t ha^{-1} + FYM@ 10 t ha^{-1}	14.60	14.85	2.53	3.76	1.86	2. 63	2.38	2.51
T15: CS - Biochar@ 6 t ha^{-1} + FYM@ 10 t ha^{-1}	14.61	14.96	2.79	3.80	2.10	2. 78	2.42	2.82
T16: CS - Biochar@ 8 t ha^{-1} + FYM@ 10 t ha^{-1}	14.96	15.07	2.96	3.94	2.14	2. 80	2.48	2.95
S.Em±	0.19	0.24	0.08	0.05	0.07	0.03	0.03	0.10
C.D. (p=0.05)	0.55	0.69	0.22	0.14	0.20	0.08	0.08	0.28

3.3 Effect of Levels of Biochar on Soil Total Microbial Counts under Aerobic Rice Cultivation

3.3.1 Total microbial counts (Bacteria, Fungi and Actinomycetes) in soils

The data presented in a Fig. 1 showed that total microbial count *viz.,* bacteria, fungi and actinomycetes at different levels of CS-biochar and FYM treated plots, revealed that, the highest total microbial count was observed in the treatments that received combined CS-biochar and FYM as compared to other treatments both at panicle initiation and harvest stages of aerobic rice crop. It might be due to application of biochar and FYM which provides refuge and supply C as energy source for microorganism. Biochar and FYM are rich suppliers of different labile carbon fractions to soil which stimulates the microbial activity. Results of present study corroborate with the results of [38]. Similar findings have been reported by [39,40,21]. [41] confirmed that increased rates of biochar especially 62 and 93 t ha^{-1} to a highly weathered soil not only enhanced microbial populations and activity in soil up to 45 per cent but also favoured the plant microbe interactions through their effects on nutrient availability and modification of habitat. Biochar has a role in changing soil microorganism abundance. A study of [42] indicated that microbial abundance increased from 10 times after application of biochar at the rate of 30 t ha-1. These changes have direct effects onnutrient cycles and indirect effect on plant growth.

3.4 Effect of Levels of Biochar on Soil Enzymes Activities under Aerobic Rice Cultivation

3.4.1 Dehydrogenase activity

The dehydrogenase activity in soil increased with increasing in the levels of CS-biochar and FYM, and also their combined application over absolute control (T_1). Higher dehydrogenase activity in soil was found in the treatments receiving combined application of CS-biochar and FYM over individual application of CS-biochar and FYM (Table 7). Among the treatments, treatment T_{16} (CS-biochar 8 t ha^{-1} + FYM 10 t ha^{-1} + RDF) recorded significantly higher soil dehydrogenase activity (62.71 and 70.07 µg TPF g^{-1} 24 h^{-1}, respectively) followed by T_{15} (CS-biochar 6 t ha^{-1} + FYM 10 t ha^{-1} + RDF) which registered 59.33 µg TPF g^{-1} 24 h^{-1} at both panicle initiation, and harvest T_{12} (69.83 µg TPF g^{-1} 24 h^{-1}) stages and it was on par with treatment T_{16} (CS-biochar 8 t ha^{-1} + FYM 10 t ha^{-1} + RDF). Lowest dehydrogenase activity of 22.14 and 26.43 µg TPF g^{-1} 24 h^{-1} was noticed in T_1 (absolute control) treatment at both panicle initiation and harvest stages, respectively.

3.4.2 Alkaline phosphatase activity

The alkaline phosphatase activity in soil increased with increasing in the levels of CS-biochar and FYM, with their combined application over absolute control (T_1). Higher alkaline phosphatase activity in soil was found in the treatments receiving combined application of CS-biochar and FYM over individual application of biochar and FYM (Table 7). Among the treatments, treatment T_{16} (CS-biochar 8 t ha^{-1} + FYM 10 t ha^{-1} + RDF) recorded significantly higher soil alkaline phosphatase activity (39.82 µg PNP g^{-1} h^{-1}) which found superior over all other treatments at panicle initiation stage. Even at harvest stage of the treatment, T_{16} (CS-biochar 8 t ha^{-1} + FYM 10 t ha^{-1} + RDF) registered higher alkaline phosphatase activity (43.73 µg PNP g^{-1} h^{-1}) followed by T_{15} (CS-biochar 6 t ha^{-1} + FYM 10 t ha^{-1} + RDF) which recorded 39.60 µg of PNP g^{-1} h^{-1}. Lowest alkaline phosphatase activity (12.60 µg of PNP g^{-1} h^{-1}) was noticed in absolute control (T_1) treatment.

3.4.3 Urease activity

Result revealed that, urease activity in soil increased with increasing in the levels of CS-biochar and FYM, with their combined application over absolute control (T_1). Higher urease activity in soil was found in the treatments receiving combined application of CS-biochar and FYM over alone application of CS-biochar and FYM (Table 7). Higher urease activity was recorded in the T_{16} (CS-biochar 8 t ha^{-1} + FYM 10 t ha^{-1} + RDF) treatment at panicle initiation and harvest stages *viz.,* 783.18 and 755.13 µg NH_4^+-N g^{-1} hr^{-1}, respectively, followed by T_{15} (737.09 µg NH_4^+-N g^{-1} hr^{-1}) which was on par with T_{12} (725.31 µg NH_4^+-N g^{-1} hr^{-1}) at panicle initiation stage, whereas at harvest T_{15} (CS-biochar 6 t ha^{-1} + FYM 10 t ha^{-1} + RDF) treatment was on par with T_{16} (CS-biochar 8 t ha^{-1} + FYM 10 t ha^{-1} + RDF). Lowest urease activity was observed in T_1 (absolute control) treatment at both panicle initiation (290.71 µg NH_4^+- N g^{-1} hr^{-1}) and harvest stages (188.41 µg NH_4^+- N g^{-1} hr^{-1}).

Table 7. Effect of levels of biochar on soil enzymes activities at different crop growth stages under aerobic rice cultivation

Treatments	Dehydrogenase activity (µg of TPF g^{-1} 24 hr^{-1})		Alkaline phosphatase activity (µg PNP g^{-1} hr")		Urease activity (µg NH_4^+-N g^{-1} hr^{-1})	
	Panicle initiation	**Harvest**	**Panicle initiation**	**Harvest**	**Panicle initiation**	**Harvest**
T1: Absolute Control	22.14	26.43	12.08	12.60	290.71	188.41
T2: 100:50:50 NPK kg ha^{-1} (Only RDF)	36.24	37.31	24.61	25.19	397.09	227.09
T3: FYM@ 5 t ha^{-1}	50.20	54.61	30.08	32.72	398.16	381.12
T4: FYM@ 10 t ha^{-1} (POP)	51.40	54.83	32.36	32.80	398.96	406.81
T5: CS - Biochar@ 2 t ha^{-1}	47.77	53.78	24.93	30.47	481.16	389.31
T6: CS - Biochar@ 4 t ha^{-1}	49.00	56.13	25.39	30.70	498.34	471.67
T7: CS - Biochar@ 6 t ha^{-1}	51.67	59.42	25.72	32.10	533.61	506.00
T8: CS - Biochar@ 8 t ha^{-1}	52.83	64.21	25.80	33.17	633.18	573.31
T9: CS - Biochar @2 t ha^{-1} + FYM @ 5 t ha^{-1}	53.34	59.98	30.88	36.20	693.60	563.02
T10: CS - Biochar@ 4 t ha^{-1} + FYM@ 5 t ha^{-1}	54.84	60.13	31.46	36.64	708.12	608.31
T11: CS - Biochar@ 6 t ha^{-1} + FYM@ 5 t ha^{-1}	55.17	60.97	33.91	37.92	718.68	649.22
T12: CS - Biochar@ 8 t ha^{-1} + FYM@ 5 t ha^{-1}	56.70	69.83	35.13	39.08	725.31	693.41
T13: CS - Biochar@ 2 t ha^{-1} + FYM@ 10 t ha^{-1}	54.31	59.18	32.83	35.00	700.38	693.38
T14: CS - Biochar@ 4 t ha^{-1} + FYM@ 10 t ha^{-1}	56.78	61.27	35.19	37.63	720.63	700.19
T15: CS - Biochar@ 6 t ha^{-1} + FYM@ 10 t ha^{-1}	59.33	61.83	36.40	39.60	737.09	713.63
T16: CS - Biochar@ 8 t ha^{-1} + FYM@ 10 t ha^{-1}	62.71	70.07	39.82	43.73	783.18	755.13
S.Em±	1.81	2.01	1.24	1.48	20.85	18.69
C.D. (p=0.05)	5.23	5.81	3.57	4.27	60.22	53.98

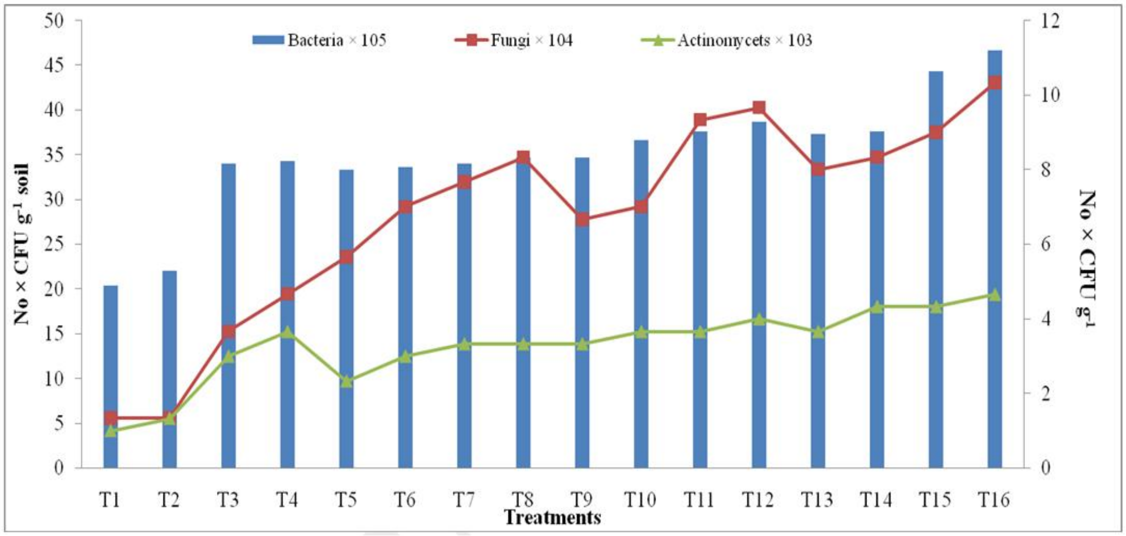

Fig. 1. Effects of levels of biochar on soil microbial population at harvest under aerobic rice cultivation

T_1: Absolute Control; T_2: 100:50:50 NPK kg ha^{-1} (Only RDF); T_3: FYM @ 5 t ha^{-1}; T_4: FYM @ 10 t ha^{-1} (POP); T_5: CS - Biochar @ 2 t ha^{-1}; T_6: CS - Biochar @ 4 t ha^{-1}; T_7: CS - Biochar @ 6 t ha^{-1}; T_8: CS - Biochar @ 8 t ha^{-1}; T_9: CS - Biochar @ 2 t ha^{-1} + FYM @ 5 t ha^{-1}; T_{10}: CS - Biochar @ 4 t ha^{-1} + FYM @ 5 t ha^{-1}; T_{11}: CS - Biochar @ 6 t ha^{-1} + FYM @ 5 t ha^{-1}; T_{12}: CS - Biochar @ 8 t ha^{-1} + FYM @ 5 t ha^{-1}; T_{13}: CS - Biochar @ 2 t ha^{-1} + FYM @ 10 t ha^{-1}; T_{14}: CS - Biochar @ 4 t ha^{-1} + FYM @ 10 t ha^{-1}; T_{15}: CS - Biochar @ 6 t ha^{-1} + FYM @ 10 t ha^{-1}; T_{16}: CS - Biochar @ 8 t ha^{-1} + FYM @ 10 t ha^{-1};

Over all, enzyme activities increased with increased in levels of CS-biochar and FYM addition. Higher enzymes activity was noticed at harvest stage of crop over panicle initiation stage in soil. Among different enzyme activities, urease enzyme (755.13 µg NH_4^+- N g^{-1} hr^{-1}) was found dominant soil enzyme followed by dehydrogenase enzyme (70.07 µg TPF g^{-1} 24 h^{-1}) and alkaline phosphatase enzyme (43.73 µg PNP g^{-1} h^{-1}) especially in the treatment, T_{16} (CS-biochar 8 t ha^{-1} + FYM 10 t ha^{-1} + RDF). However, urease enzyme activity decreased with maturity of crop.

The higher activity of urease, alkaline phosphatase and dehydrogenase activity was significantly differing in the treatments supplied with powdered coconut shell biochar and FYM at panicle initiation and harvest stages of crop (Table 7). Higher urease and alkaline phosphatase activity in soil treated with CS-biochar addition might be due to the increase in oxidative capacity of soil microorganisms and the hydrolysis reactions of urea. Similar result was observed by [43]. Combined application of *Pseudomonas* strains and arbiscular mycorhizal fungi increased urease and alkaline phosphatase activity in the rhizosphere of wheat [44]. Higher alkaline phosphatase activity in soils was discernible in the soils supplied with biochar, probably due to more pH of CS-biochar. The carbon content and available nutrients in the biochar are a good source for microorganisms resulting in an increase in degradable composition in biochar treated soil and consequently enhancing the microbial activity [45]. Increase in dehydrogenase activity is considered to be correlated with the availability of organic matter in the soil [46]. [47] reported that application of biochar increased overall soil enzymatic activity.

4. CONCLUSION

Coconut shell biochar was found to be a rich source of carbon (48.37 %) and nutrients (N, K, Ca, Mg) with alkaline pH, medium EC, lower density, higher maximum holding capacity and field capacity with high C:N ratio which helps in enhanced the soil properties. From the field investigation the combined application of biochar and FYM with recommended dose fertilizers, resulted the most favourable physical, physico-chemical, chemical and biological properties of soil compared to biochar, FYM and RDF applied individually. The coconut shell biochar is a high C:N ratio organic material, that could be reduced by the application of FYM. Since, FYM is a good source of microorganisms and hastens the better mineralization rate and increased the efficiency of biochar in soil. The study area is located in the southern transition zone of Karnataka state, India with *Typichaplustalf* with sandy loam texture, where soils are infertile, acidic and drastically mineralized. Based on the findings in this study, chemical fertilizer application to soils could be associated with biochar and FYM, through which multi-benefits (e.g., soil amendment, nutrient sources, environment protection, C sequestration) could be obtained simultaneously.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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