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Soil modification through biochar: Changes in physical, chemical and biological properties of soil

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Abstract
A field experiment was conducted to study "Soil Modification through Biochar: Changes in Physical, Chemical and Biological Properties of soil" at ICAR-Krishi Vigyan Kendra farm, Kalaburagi farm during Rabi season, 2021-22. The experiment was laid out in a Randomized Complete Block Design (RCBD) having eight treatments *viz*., Absolute control, Recommended dose of fertilizers only, Biochar @ 2 t ha^{-1}, Biochar @ 4 t ha^{-1}, 50% RDF + Biochar @ 2 t ha^{-1}, 50% RDF + Biochar @ 4 t ha^{-1}, 100% RDF + Biochar @ 2 t ha^{-1} and 100% RDF + Biochar @ 4 t ha^{-1}. The results revealed that significantly Difference in physical properties *viz*., Lower Bulk density (1.37 Mg m^{-3}) and Maximum water holding capacity (58.79%) at harvest and Significantly higher Chemical properties *viz*., soil pH (8.31), EC (0.48 dS m^{-1}), organic carbon (6.66 g kg^{-1}), Available Nitrogen (234.10 kg ha^{-1}), Available Phosphorus (38.65 kg ha^{-1}), Available Potassium (391.63 kg ha^{-1}), and Micronutrients *viz*., higher value of extractable zinc (0.53 mg kg^{-1}), Fe (3.21 mg kg^{-1}), manganese (4.15 mg kg^{-1}) and copper (1.82 mg kg^{-1}) and also significantly higher soil microbial population *viz*., bacterial population (19.42 × 106 CFU g^{-1}), fungal population (4.53 × 103 CFU g^{-1}) and actinomycetes population (4.12 × 104 CFU g^{-1}) were recorded with the application of 100% RDF + biochar @ 4 t ha^{-1} compared to absolute control and other treatments.

Keywords: Biochar, RDF, MWHC, pH and EC

Introduction
Biochar is produced by the thermochemical decomposition of organic material (crop residues and wood wastes) under partial or complete exclusion of oxygen (pyrolysis), at sufficiently higher temperature range of 450 °C to 600 °C has been the focus of researchers for the past several years. Converting cheap, abundant crop straws into biochar and applying it to soils may have significant agricultural and environmental benefits (Wang *et al.*, 2013) [31] Biochar is highly porous, usually alkaline and exhibit large specific surface area (Glaser *et al*., 2002, Downie *et al.*, 2009) [11, 7]. Due to these inherent chemical and physical properties, biochar can potentially influence a number of soil properties including soil pH, porosity, bulk density and water holding capacity (Glaser *et al*., 2002; Chan *et al*., 2007) [11, 4].
Cicer arietinum L. commonly called chickpea or Bengal gram is one of the major pulse crops most cultivated in the area receiving low rainfall during Rabi season in India. Chickpea is a member of legumes family, fabaceae and sub family papilionaceae. Gram considered as the third largest produced food legume (FAO, 2013) globally after common beans (Phaseolus vulgaris L.) and field pea (*Pisum sativum* L.). Chickpea accounts for 20 per cent of the global pulse production and it is grown in more than 55 countries under varied environmental conditions across the world. India is the largest chickpea producing country contributing around 70 per cent of the world's total production followed by Turkey. In India, it is grown in the area of 9.44 m ha with a production of 10.13 Mt and productivity of 1076 kg/ha. The major Bengal-gram growing states are Madhya Pradesh, Maharashtra, Rajasthan and Karnataka. In Karnataka, it is cultivated in an area of 1.09 mha with the production of 0.57 mt (Anon., 2019). The biochar is a sustainable tool to restore the degraded soil ecosystems and it is considered as ecofriendly technique as compared to synthetic fertilizers. Biochar has become a promising stabilizer in methane mitigation in agriculture sector and may help to reduce greenhouse emissions as well (Dar *et al*., 2019) [6]. The utility of the biochar from various waste is a promising way recycling

and it could improve the health of the degraded soils, poor soils and barren lands (Elangovan *et al*., 2022) [9]. The direct seeded rice recorded the highest chlorophyll content, nitrogen and phosphorus uptake and quality parameters resulted with biochar @ 7.5 t ha^{-1} treatment (Sai Surya Gowthami *et al*., 2022) [27]. Biochar, a carbon-rich product, boosts soil fertility, sequesters carbon, and reduces greenhouse gas emissions (Lal *et al*., 2024) [17].

Effectiveness in retaining most nutrients and keeping them available to plants are the most unique characteristics of the biochar than the other organic matter (leaf litter, compost and manures) and improve the crop yield by decreasing environmental pollution due to nitrogen. Retuning biochar to the field can quickly improve soil carbon storage, nitrogen content and soil fertility. It can also reduce the emission of greenhouse gases and improve crop yields. Biochar has a stable and a long-term potential in carbon sequestration.

Materials and Methods

The experiment was conducted at ICAR-Krishi Vigyan Kendra farm, Kalaburagi farm during Rabi season, 2021-22. Kalaburagi is situated in the North Eastern Dry Zone (Zone-2) of Karnataka between 170 34' N latitude and 760 79' E longitude with an altitude of 478 meters above the mean sea level. The experiment was laid out in a Randomized Complete Block Design (RCBD) having eight treatments and are replicated thrice *viz*., Absolute control, Recommended dose of fertilizers only, Biochar @ 2 t ha^{-1}, Biochar @ 4 t ha^{-1}, 50% RDF + Biochar @ 2 t ha^{-1}, 50% RDF + Biochar @ 4 t ha^{-1}, 100% RDF + Biochar @ 2 t ha^{-1} and 100% RDF + Biochar @ 4 t ha^{-1}. 100% RDF- Recommended dose of fertilizer (25:50:00 kg ha^{-1}), Farm yard manure @ 5 t ha^{-1} is and Zinc Sulphate (21%) @ 5 kg ha^{-1} is common for all the treatments except T_1. Sowing was done on 9th November, 2021. The soil of the experimental site was shallow to medium black and slightly alkaline (8.10) with an electrical conductivity of 0.35 ds m^{-1}. The soil organic carbon content (0.53%). The macronutrients like available nitrogen (198 kg ha^{-1}), available phosphorus (28.6 kg ha^{-1}) and available potassium (370 kg ha^{-1}) and available Micronutrients like available Iron (2.66 mg kg^{-1}), available Manganese (3.15 mg kg^{-1}), available Zinc (0.28 mg kg^{-1}) and available Copper (1.18 mg kg^{-1}), respectively.

Results and Discussion

Change in physical properties of soil

Bulk Density (Mg m^{-3})

The data obtained on effect of biochar on soil physical properties were presented in the table 1. Application of biochar at different levels showed slight difference in soil bulk density values after the harvest of the chickpea crop. Higher bulk density of 1.43 Mg m^{-3} was recorded in absolute control. The lower bulk density of (1.37 Mg m-3) was recorded with the application of 100% RDF + biochar @ 4 t ha^{-1}. The bulk density of soil at harvesting stage of chickpea crop was slightly low but not significant from biochar applied to not apply treatments. A slight reduction in bulk density was noticed in soils treated with biochar.

The biochar addition directly leads to decrease in bulk density of soils because of its lower density that induced soil aggregation compared to mineral soils and made the soil more porous. In the investigation, 100% RDF + biochar @ 4 t ha^{-1} recorded lower soil bulk density. A dilution effect caused by the addition of light weight, low density material like biochar to a soil might partly result in decrease in soil bulk density. These results are similar with the findings reported by Lu *et al*. (2015). Esmaeelnejad *et al*. (2016) [8] reported the decrease in bulk density of soil with the incorporation of biochar which leads to increase in soil porosity.

Maximum water holding capacity (MWHC)

The results in the Table 1 indicated that with the addition of biochar the maximum water holding capacity (MWHC) of soil was significantly influenced with the increasing rate of biochar application.

Among various treatments, the maximum water holding capacity varied from 50.01% to 58.79% the significantly higher maximum water holding capacity (58.79) was observed with the application of 100% RDF + biochar @ 4 t ha-1. However, this was found to be on par with application of 50% RDF + biochar @ 4 t ha^{-1} (57.90%). Significantly, the lower maximum water holding capacity (50.01%) was recorded in absolute control where biochar was not added. Since biochar is more porous in nature and has high specific surface area, on addition to soil, it generally decreases soil bulk density which leads to increase in porosity and water holding capacity of soils. In present investigation, 100% RDF + biochar @ 4 t ha^{-1} has recorded the higher MWHC. The remaining biochar added treatments also showed increase in MWHC when compared to treatments without the supply of biochar.

Increase in MWHC of soil with biochar addition was also observed by Verheijen *et al*., 2010 [30] since biochar addition increases specific surface of soil. Herath *et al*. (2013) [13] also noticed increase in MWHC with addition of biochar because it increases soil microporosity in sandy soils and also due to high absorptive nature of biochar for water.

Change in chemical properties of soil

Soil reaction (pH)

The data in the Table 2 revealed that slight increasing trend in pH at higher application rates of biochar compared to control treatment. Due to alkaline nature of biochar, up on its addition to soil caused slight increase in soil pH.

After the harvest of the chickpea crop, higher soil pH of 8.31 and 8.27 was recorded with the application of 100% RDF + biochar @ 4 t ha^{-1} and 100% RDF + biochar @ 2 t ha^{-1}, respectively. An increased trend of soil pH with increased rates of biochar application from 2 t ha-1 to 4 t ha^{-1} was found but the differences were non-significant. The lowest soil pH (8.04) was observed in absolute control.

With the application of biochar, the increase in pH might be due to alkaline nature of biochar (9.10). In the present investigation, numerical but non-significant increase in soil pH was observed with the biochar application compared to untreated biochar plots. Therefore, 100% RDF + biochar @ 4 t ha^{-1} recorded the higher soil pH. Yuan and Xu (2011) also observed an increase in soil pH due to biochar addition which might be due to the release of basic cations in soil. The results of Nigussie *et al*., 2012 [25] also supported the present results of increase in soil pH with the biochar addition. This could be due to high surface area and porous nature of biochar that increased the CEC of the soil and enhanced the Al and Fe to bind with the exchange sites of biochar which in turn decreased the exchangeable Al and soluble Fe in biochar amended soils. Gautam *et al*., (2017) [10] opined that, alkaline nature of biochar upon addition to soil could have contributed towards increasing the soil pH.

Electrical conductivity of soil (EC)

The data presented in the Table 2 revealed that there was non-significant difference but a numerical increase in soil EC with

the biochar addition. After the harvest of chickpea crop, higher EC (0.48 dS m^{-1}) was observed with the application of 100% RDF + biochar @ 4 t ha^{-1} followed by the application of 100% RDF + biochar @ 2 t ha-1 (0.45 dS m^{-1}) and 50% RDF + biochar @ 4 t ha^{-1} (0.42 dS m^{-1}) and lower (0.32 dS m^{-1}) value was recorded in absolute control.

The numerical increase in EC with the application of biochar might be due to salt residues in biochar dominated by carbonates of alkali and alkaline earth metals. In the present investigation, 100% RDF + Biochar @ 4 t ha^{-1} recorded higher EC. These results are in similarity with findings of Nigussie *et al*., 2012 [25].

Organic carbon content of soil (g kg^{-1})

The organic carbon values presented in Table 2 indicated that, there was a significant difference in soil organic carbon content among the various treatments after the chickpea harvest. Soil organic carbon content after chickpea harvest varied from 5.11g kg-1 to 6.66 g kg^{-1}. Among the treatments, significantly higher organic carbon value (6.66 g kg^{-1}) was recorded with the application of 100% RDF + biochar @ 4 t ha^{-1} followed by 50% RDF + biochar @ 4 t ha-1 (6.29 g kg^{-1}) and with application of 100% RDF + Biochar @ 2 t ha^{-1} (6.10 g kg^{-1}). Significantly lowest soil organic carbon was reported in absolute control (5.11 g kg^{-1}) which did not received external nutrient supply or modification.

The increased rate of application of biochar levels increased the organic carbon content in soil. The higher organic carbon levels in biochar treated soils show the recalcitrant organic carbon in biochar which is immune to mineralization and further loses. In the present investigation, 100% RDF + biochar @ 4 t ha^{-1} recorded higher soil organic carbon. The soil organic carbon stock named carbon sequestration will then be improved. Lehmann and Randon (2005) [18] and Solomon *et al*. (2009) [29] have also reported high organic carbon in soils where biochar was used. The special properties of stable C in biochar and high surface area, high charge per unit area, occurrence of specific functional surface groups and ash content have a beneficial impact on chemical properties of the soil. Application of biochar increased SOC, pH, EC, CEC and exchangeable bases in soil. These results were accordance with the findings of Hass *et al*. (2012) [12] and Anteneh *et al*. (2014) [1].

Soil Available Nitrogen (kg ha^{-1})

Effect of biochar application on soil available nitrogen is presented in Table 3 and which indicated, that there was a significant influence on soil available nitrogen with the combined application of fertilizers and biochar. The available nitrogen after the harvest of the chickpea crop was recorded significantly higher (234.10 kg ha^{-1}) value with the application of 100% RDF + biochar @ 4 t ha^{-1} followed by 100% RDF + biochar @ 2 t ha^{-1} (228.83 kg ha^{-1}) and application of 50% RDF + biochar @ 2 t ha^{-1} (226.53 kg ha^{-1}) which was found to be on par with the application of 100% RDF + biochar @ 4 t ha^{-1}. Significantly lower soil available nitrogen (185.79 kg ha^{-1}) was reported in absolute control where no external nutrient supply was added and without biochar application. Slight increase in available nitrogen was noticed with increased rates of biochar application from 2 t ha^{-1} to 4 t ha^{-1}. Although biochar itself is not a direct source of nitrogen but it acts as micro habitat for added N fertilizer (added fertilizer which was trapped inside the biochar pores) and making it available at later stages of crop. Biochar also reduces leaching losses of N from soil. In present investigation, 100% RDF + biochar @ 4 t ha^{-1} recorded higher soil available nitrogen.

Studies of Nelissen *et al*. (2012) [24] concluded that, increase in nitrogen content by biochar addition was due to enhanced nitrification rate because biochar absorbed the potential inhibitors of nitrification such as monoterpenes and various polyphenolic compounds. Shen *et al*. (2016) [28] reported that, biochar application enhanced soil nitrogen availability to the plant, since it's believed act as soil conditioner, altering the soil chemical and microbial properties favorably, protecting nitrogen from losses and resulting in an increased availability.

Soil Available Phosphorus (kg ha^{-1})

The data presented in Table 3 and indicated that, there was a significant influence on soil available phosphorus in biochar applied treatments when compared to absolute control. After the harvest of the chickpea crop, significantly higher available phosphorus (38.65 kg ha-1) was recorded with the application of 100% RDF + biochar @ 4 t ha-1. However, it was found to be on par with the application of 100% RDF + biochar @ 2 t ha-1 (37.80 kg ha^{-1}) and treatment with receiving 50% RDF + biochar @ 4 t ha^{-1} (37.22 kg ha^{-1}). Significantly, lower available phosphorus (22.21 kg ha^{-1}) was recorded in absolute control. The available phosphorus was higher in 100% RDF and RDF + biochar applied treatments than only biochar applied treatments and control, because of direct supply of soluble phosphorus in fertilizer added soil.

Due to the ability of biochar to retain anions, the synergistic effect of biochar and fertilizer was observed which improved available phosphorus. In the present investigation, 100% RDF + biochar @ 4 t ha^{-1} recorded the higher soil available phosphorus. The increase in pH values leads to an increase in the number of negative charges on soil colloids, leading to more anionic repulsion and reduction in sorption of phosphate anions leading to a greater quantity of free phosphorus in soil system. Similar results were reported by Mukherjee *et al*. (2011) [22].

Opala *et al*. (2012) [6] supported these results of significant increase in available phosphorus with the addition of biochar by improved microbial activity and microbially mediated mineralization of soil phosphorus to available phosphorus. Further, biochar application increased soil available phosphorus due to the effect of biochar on soil reaction of acid soils which increased the mobility of phosphate ions in the soil solution (Husien *et al*., 2017) [14].

Soil Available Potassium (kg ha^{-1})

Due to biochar application the available potassium content in soil increased significantly along with inorganic fertilizers compared to absolute control (Table 3). The available potassium content after the harvest of the chickpea crop was found to be significantly higher (391.63 kg ha^{-1}) with the application of 100% RDF + biochar @ 4 t ha^{-1}. However, it was on par with application of 100% RDF + biochar @ 2 t ha^{-1} (383.71 kg ha^{-1}) and with application of 50% RDF + biochar @ 4 t ha^{-1} (378.80 kg ha^{-1}). Significantly lower available potassium (292.15 kg ha^{-1}) was reported in absolute control. In 100% RDF and RDF + Biochar applied treatments, the available potassium content was significantly higher than control. The soil available potassium increased with increased rates of application of biochar because it contains some amount of ash which was rich in potassium. Among the different biochar treated plots, 100% RDF + biochar @ 4 t ha^{-1} recorded highest soil available potassium.

Increased potassium was primarily responsible for the immediate beneficial impact of biochar inputs on nutritional abundance. The biochar produced high ash which has more potassium content relative to other main nutrients, so the

potassium level improved substantially by adding ash rich biochar to soils. These results are in conformity with the findings of Lehmann *et al*. (2003) [19]. Bindu *et al*. (2016) [3] also noticed that, high cation exchange capacity of biochar represents its ability to electrostatically sorb or attract cations like K+ could be the reason for increased availability of potassium in soil and the carbonate and carboxylate functional groups of biochar are responsible for retention of potassium along with other nutrients.

DTPA extractable Zinc (mg kg^{-1})

Due to the application of different amounts of biochar, the DTPA extractable zinc content was found to vary significantly between treatments (Table 4). Significantly, higher value of extractable zinc (0.53 mg kg^{-1}) was reported with 100% RDF + biochar @ 4 t ha^{-1} compared to absolute control (0.24 mg kg^{-1}). However, it was found to be on par with 100% RDF + biochar @ 2 t ha^{-1} (0.52 mg kg^{-1}) and 50% RDF + biochar @ 4 t ha^{-1} (0.50 mg/kg). The lower DTPA extractable zinc was recorded in absolute control.

DTPA extractable Iron (mg kg^{-1})

The data presented in Table 4 showed that, after the harvest of chickpea, soil iron content was not influenced by the application of various rates of biochar. The higher value of Fe (3.21 mg kg^{-1}) was found with 100% RDF + biochar @ 4 t ha^{-1} followed by the application of 100% RDF + biochar @ 2 t ha^{-1} (3.14 mg kg^{-1}) and 50% RDF + biochar @ 2 t ha^{-1} (3.04 mg kg^{-1}). The lower value (2.06 mg kg^{-1}) was recorded in absolute control which did not received any external supply of nutrients and biochar source.

DTPA extractable Manganese (mg kg^{-1})

The data presented in Table 4 indicated that, application of biochar does not influenced significantly the soil DTPA extractable manganese, however it showed a slight increased trend towards biochar application. The highest manganese (4.15 mg kg^{-1}) content was observed in 100% RDF + biochar @ 4 t ha^{-1} accompanied by 100% RDF + biochar @ 2 t ha^{-1} (4.00 mg kg^{-1}) and 50% RDF + biochar @ 4 t ha^{-1} (3.95 mg kg^{-1}) and lowest (2.93 mg kg^{-1}) in absolute control.

DTPA extractable Copper (mg kg^{-1})

The DTPA extractable copper in the soil slightly increased in the treatments but the biochar does not significantly influenced the soil DTPA extractable copper. Higher extractable copper (1.82 mg kg^{-1}) was observed with 100% RDF + biochar @ 4 t ha^{-1} followed by 100% RDF + biochar @ 2 t ha^{-1} (1.72 mg kg^{-1}) and 50% RDF + biochar @ 4 t ha^{-1} (1.71 mg kg^{-1}) and the lowest was found in absolute control. With increasing rates of biochar application (2 t ha^{-1} to 4 t ha^{-1}) non-significant increase in soil extractable copper was observed in the treatments. The biochar application does not significantly influenced the soil available micronutrient status. The biochar incorporation might lead to immobilization of micronutrients in soil. These findings were in close agreement with the findings of Namgay *et al*. (2010) and Jun and Xu (2013) [16].

Change in soil microbial population of soil

The significant influence of biochar application on total microbial count of soil was noticed and results are presented in the Fig1.

Bacterial population

Application of biochar at different levels has showed significant influence on bacterial population in the soil. Significantly, higher bacterial population (19.42 × 106 CFU g^{-1}) was recorded with the application of 100% RDF + biochar @ 4 t ha^{-1}, followed by 50% RDF + biochar @ 4 t ha^{-1} (18.64 × 106 CFU g^{-1}) and with the application of 100% RDF + biochar @ 2 t ha^{-1} (17.32 × 106 CFU g^{-1}) when compared to the treatment with the application of 100% RDF without application of biochar (14.13 × 106 CFU g^{-1}). Significantly, lowest bacterial population (13.01 × 106 CFU g^{-1}) was recorded in absolute control.

Atkinson *et al*. (2010) [2] reported that favourable properties of biochar, which upon addition to soil allowed the development of bacteria in biochar treated soil compared to control. In the present investigation, 100% RDF + biochar @ 4 t ha^{-1} recorded higher bacteria count.

Bacteria are efficient at colonizing the surfaces of porous biochar materials and can avoid being dominated by fungi due to their smaller size. Biochar induced alteration to soil pH condition and other chemical properties which favored bacterial growth. Biochar contains 75.3 per cent of carbon, it is a source of energy for microbes. Bacteria utilize this carbon and multiply very fast. Hence, higher bacterial abundance in biochar added soils was due to higher availability of organic carbon for bacterial proliferation. These results were accordance with the findings of Chen *et al*. (2013) [5] and Ming *et al*. (2016).

Fungal population

The application of biochar at different levels has showed significant influence on fungal population in the soil. Significantly, higher fungal population (4.53 × 103 CFU g^{-1}) was recorded with the application of 100% RDF + biochar @ 4 t ha^{-1}, followed by the application of 50% RDF + biochar @ 4 t ha^{-1} (4.32 × 103 CFU g^{-1}) and with the application of 100% RDF + biochar @ 2 t ha^{-1} (3.96 × 103 CFU g^{-1}) showed higher when compared to the treatment with the application of 100% RDF without application of biochar (2.01 × 103 CFU g^{-1}). Significantly, lower fungal population (1.91 × 103 CFU g^{-1}) was recorded in absolute control.

The biochar application to soil might lead to the production of certain metabolites that induce secretion of flavonoids, sesquiterpenes and strigolactones by plant roots that favoured increased colonization of plant roots by AM fungi and increased spore germination and hyphal branching of AM fungi. In the present investigation, 100% RDF + biochar @ 4 t ha^{-1} recorded higher fungal count. Significant increase in fungal population with the biochar application was due to availability of sufficient food and energy source in the form of organic carbon. These results were corroborated with the findings of Xie *et al*. (1995) [33] and Zhang *et al*. (2018) [36].

Actinomycetes population

The application of biochar at different levels has showed significant influence on actinomycetes population in the soil. Significantly higher actinomycetes population (4.12 × 104 CFU g^{-1}) was reported with the application of 100% RDF + biochar @ 4 t ha^{-1}, followed by the application of 50% RDF + biochar @ 4 t ha^{-1} (3.98 × 104 CFU g^{-1}) and with the application of 100% RDF + biochar @ 2 t ha^{-1} (3.64 × 104 CFU g^{-1}) showed higher when compared to the treatment with the application of 100% RDF without application of biochar (2.25×104 CFU g^{-1}). Significantly, lower actinomycetes population was recorded (2.08 × 104 CFU g^{-1}) in absolute control.

Increase in soil actinomycetes population might be due to their ability to degrade persistent and complex substrates like biochar (Johnsen *et al*., 2002) [15]. In the present investigation, 100% RDF + Biochar @ 4 t ha^{-1} recorded higher actinomycetes count.

Actinomycetes are sensitive to low pH and increase in pH due to biochar application, caused increased actinomycetes population in soil. Significant increase actinomycetes population with biochar addition was reported by Yun *et al*. (2017) [35] and Watzinger *et al*. (2014) [32].

Table 1: Physical properties of soil after the harvest of chickpea as influenced by application of biochar

Treatments	Bulk Density (Mgm^{-3})	MWHC (%)
T_1-Absolutecontrol	1.43	50.01
T_2-RDFonly(25:50:00)	1.43	51.20
T_3-Biochar@2tha^{-1}	1.42	52.10
T_4-Biochar@4tha^{-1}	1.41	53.45
T_5-50%RDF+Biochar@2tha^{-1}	1.40	54.40
T_6-50%RDF+Biochar@4tha^{-1}	1.38	57.90
T_7-100%RDF+Biochar@2tha^{-1}	1.40	57.20
T_8-100%RDF+Biochar@4tha^{-1}	1.37	58.79
S.Em.±	0.07	0.48
CD @5%	NS	1.47
Initial values	1.45	51.68

Table 2: Chemical properties of soil after harvest of the chickpea as influenced by application of biochar

Treatments	pH(1:2.5)	EC(dSm^{-1})	Organic carbon(gkg^{-1})
T_1-Absolutecontrol	8.04	0.32	5.11
T_2-RDFonly(25:50:00)	8.16	0.36	5.21
T_3-Biochar@2tha^{-1}	8.12	0.33	5.33
T_4-Biochar@4tha^{-1}	8.14	0.34	5.37
T_5-50%RDF+Biochar@2tha^{-1}	8.20	0.38	5.56
T_6-50%RDF+Biochar@4tha^{-1}	8.24	0.42	6.29
T_7-100%RDF+Biochar@2tha^{-1}	8.27	0.45	6.10
T_8-100%RDF+Biochar@4tha^{-1}	8.31	0.48	6.66
S.Em.±	0.40	0.06	0.05
CD @5%	NS	NS	0.15
Initial values	8.10	0.35	5.53

Table 3: Influence of biochar application on status of available major nutrients in soil after harvest of chickpea

Treatments	N(kg ha^{-1})	P_2O_5($kgha^{-1}$)	K_2O($kgha^{-1}$)
T_1-Absolutecontrol	185.79	22.21	292.15
T_2-RDFonly(25:50:00)	209.73	31.90	329.25
T_3-Biochar@2tha^{-1}	193.10	25.40	302.94
T_4-Biochar@4tha^{-1}	201.29	28.15	315.50
T_5-50%RDF+Biochar@2tha^{-1}	215.79	33.10	338.78
T_6-50%RDF+Biochar@4tha^{-1}	226.53	37.22	378.80
T_7-100%RDF+Biochar@2tha^{-1}	228.83	37.80	383.71
T_8-100%RDF+Biochar@4tha^{-1}	234.10	38.65	391.63
S.Em.±	2.51	0.53	4.54
CD @5%	7.61	1.59	13.8
Initial values	198.10	28.60	370.20

Table 4: Influence of Biochar application status of available micronutrients in soil after harvest of chickpea

Treatments	Zn($mgkg^{-1}$)	Fe($mgkg^{-1}$)	Mn($mgkg^{-1}$)	Cu($mgkg^{-1}$)
T_1-Absolutecontrol	0.24	2.06	2.93	0.97
T_2-RDFonly(25:50:0)	0.39	2.65	3.48	1.27
T_3-Biochar@2tha^{-1}	0.25	2.27	3.16	1.08
T_4-Biochar@4tha^{-1}	0.29	2.38	3.23	1.16
T_5-50%RDF+Biochar@2tha^{-1}	0.40	2.70	3.60	1.35
T_6-50%RDF+Biochar@4tha^{-1}	0.50	3.04	3.95	1.71
T_7-100%RDF+Biochar@2tha^{-1}	0.52	3.14	4.00	1.72
T_8-100%RDF+Biochar@4tha^{-1}	0.53	3.21	4.15	1.82
S.Em.±	0.01	0.39	0.41	0.29
CD @5%	0.04	NS	NS	NS
Initial values	0.28	2.66	3.15	1.18

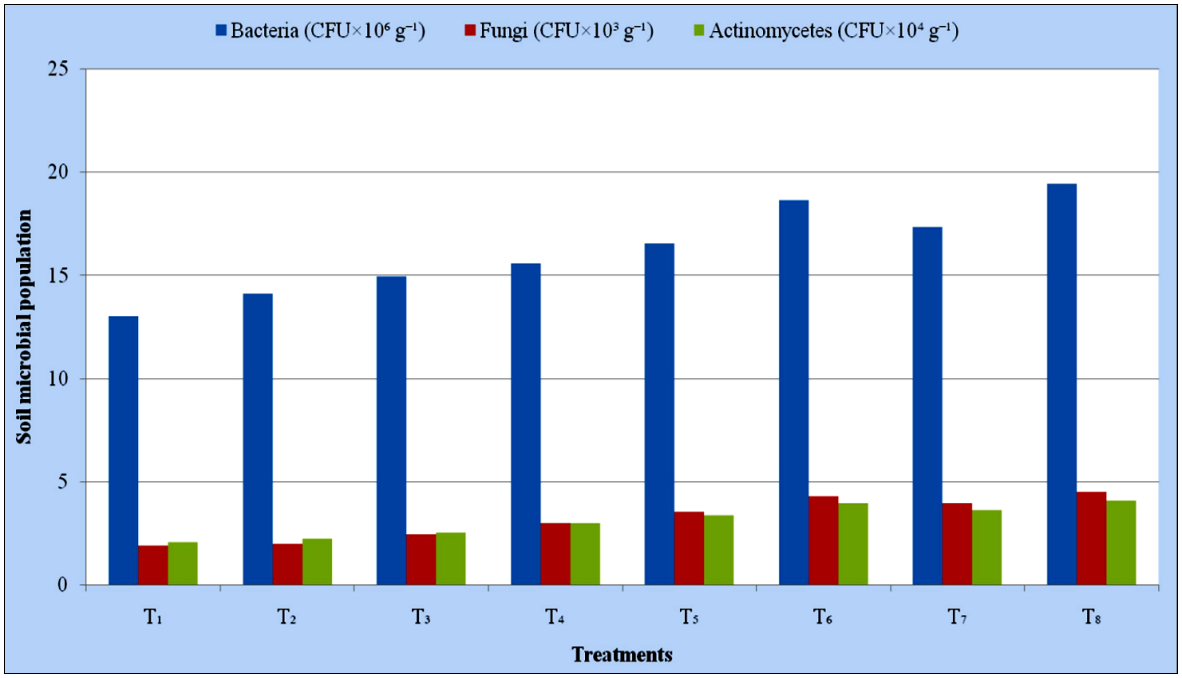

Fig 1: Influence of biochar application on soil microbial status after harvest of chickpea crop

Conclusion

Application of 100% RDF + biochar @ 4 t ha^{-1} had the best results across all the treatments. But, considering the economics of the chickpea, the treatment which received 50% RDF + biochar @ 2 t ha^{-1} had greater overall performance. It indicated that use of biochar in soil management enhancing the physical, chemical and Biological properties of soil thereby increasing soil fertility and productivity.

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