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Assessment of Biochar Effects on Essential Nutrient Uptake in Chickpea Under Field Conditions

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted during the rabi season of 2021–22 at ICAR-Krishi Vigyan Kendra, Kalaburagi, to assess the effects of biochar on essential nutrient uptake in chickpea under field conditions. The study employed a randomized complete block design (RCBD) with eight treatments: absolute control, recommended dose of fertilizers (RDF) alone, biochar at 2 t ha^{-1}, biochar at 4 t ha^{-1}, 50% RDF + biochar at 2 t ha^{-1}, 50% RDF + biochar at 4 t ha^{-1}, 100% RDF + biochar at 2 t ha^{-1}, and 100% RDF + biochar at 4 t ha^{-1}. Significant differences in nutrient concentrations were

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observed among the treatments. The application of 100% RDF combined with biochar at 4 t ha^{-1} resulted in the highest nutrient concentrations in both grain and stover—nitrogen at 3.62% and 1.25%, phosphorus at 0.51% and 0.30%, and potassium at 1.31% and 1.69%, respectively. In contrast, the absolute control recorded the lowest nutrient concentrations. The same treatment (100% RDF + biochar at 4 t ha^{-1}) also resulted in the highest nutrient uptake, with nitrogen uptake of 52.01 kg ha^{-1} in grain and 22.10 kg ha^{-1} in stover, phosphorus uptake of 7.32 kg ha^{-1} in grain and 5.26 kg ha^{-1} in stover, and potassium uptake of 18.80 kg ha^{-1} in grain and 29.88 kg ha^{-1} in stover.

Keywords: Biochar; RDF; uptake; grain and stover.

1. INTRODUCTION

"Biochar is a carbon-rich and porous material produced through the thermal decomposition of biomass, such as plant residues, agricultural waste, or wood, under controlled oxygen-limited conditions. This process, known as pyrolysis, involves heating the biomass to high temperatures in the absence or near absence of oxygen, preventing complete combustion. The result is a stable form of charcoal that contains a well-structured network of pores called biochar. As a stable carbon-rich material, biochar promotes plant growth and increases crop yields by enhancing microbial activity. Biochar is black, highly porous, lightweight, fine-grained material with large surface area values. Biochar characteristics, such as microbial activity, mineral and nutrient binding, and soil water holding capacity (WHC), depend on the physical structure, pore size, and surface area of the type of feedstock used to produce the biochar" (Tomczyk et al., 2020).

"Cicer arietinum L. commonly called chickpea or Bengalgram 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. Chickpea has ability to form nitrogen-fixing nodules via interaction with Rhizobia and it maintains the soil nutrient level. Chickpea plays a significant role in improving soil fertility by fixing the atmospheric nitrogen. Chickpea meets 80 per cent of its N requirement from symbiotic nitrogen fixation and can fix up to 140 kg N per hectare per year from the air" (Flowers *et al*., 2010). "It 1eaves substantial amount of residual nitrogen for subsequent crops and adds plenty of organic matter to improve the soil health and fertility. Because of its deep tap root system, chickpea can withstand drought conditions by extracting water from deeper layers in the soil profile" (Gupta *et al*., 2012).

"Chickpea is highly nutritious crop where its seeds containing 23 per cent of protein, 64 per cent of carbohydrates, 47 per cent of starch, 5per cent off at, 6 per cent of crude fiber, 6 per cent of soluble sugar and 3 per cent of ash, minerals such as calcium (202mg), phosphorous(312mg), iron(10.2mg), vitamin C(3.0mg), calorific value(360 cal), small amounts of B complex, fiber (3.9 g) and moisture (9.8 g). Predominantly chickpea is being consumed as dhal or variety of snack foods, sweets and condiments. Husk and split beans are useful as livestock feed. Acidic liquid from glandular hairs of the plant contains 94 per cent of malic acid and 6 per cent of oxalic acid, has medicinal value and used in preparation of vinegar" (Ferguson *et al*., 2010).

In recent years, biochar has emerged as an organic amendment with mineral nutrient elements and hold a promise to improve the soil quality and yield of crops. The biochar is found to have a positive impact on soil fertility, resulting in an increase in crop yield without causing a hazard to soil and water environment. Moreover, its production and utilizations on a commercial basis is seems to be an attractive avenue and a sustainable method of carbon sequestration in agriculture. 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.

2. MATERIALS AND METHODS

A field experiment was conducted during the rabi season of 2021–22 at the ICAR-Krishi Vigyan Kendra farm in Kalaburagi, located in the North Eastern Dry Zone (Zone-2) of Karnataka. The site is geographically situated at 17°34' N latitude and 76°79' E longitude, with an elevation of 478 meters above mean sea level. The study employed a Randomized Complete Block Design (RCBD) with eight treatment combinations, each replicated three times.

The treatments included: absolute control, recommended dose of fertilizers (RDF) alone, biochar application at 2 t/ha and 4 t/ha, 50% RDF combined with biochar at 2 t/ha and 4 t/ha, and 100% RDF combined with biochar at 2 t/ha and 4 t/ha. The RDF applied consisted of 25:50:00 kg/ha of N:P:K, supplemented with 5 t/ha of farmyard manure and 5 kg/ha of zinc sulphate (21%), uniformly applied to all treatments except the control (T1). Chickpea sowing was carried out on 9th November 2021.

The experimental soil was classified as shallow to medium black soil, slightly alkaline in reaction (pH 8.10), with an electrical conductivity of 0.35 dS/m. The soil had an organic carbon content of 0.53%, and contained 198 kg/ha of available nitrogen, 28.6 kg/ha of available phosphorus, and 370 kg/ha of available potassium. In terms of micronutrients, the soil had 2.66 mg/kg of iron, 3.15 mg/kg of manganese, 0.28 mg/kg of zinc, and 1.18 mg/kg of copper.

3. RESULTS AND DISCUSSION

3.1 Concentration of major nutrients and micronutrients in grain and stover of chickpea

3.1.1 Micronutrients concentration in chickpea (Fe, Mn, Zn and Cu)

Nitrogen concentration in chickpea (%): The presented data in the Table 1 represent that, there was a significant difference between control as well as combined application of fertilizers and biochar applied treatments. The nitrogen content in grain (3.62 %), stover (1.25 %) and total (4.87 %) was found to be significantly higher with application of 100 % RDF + biochar @ 4 t ha^{-1}. However, it was found to be on par in grain (3.45 %), stover (1.20 %) and total (4.65 %) of treatments with application of 100 % RDF + biochar @ 2 t ha^{-1} and grain (3.40 %), stover (1.19 %) and total (4.59 %) which received 50 % RDF + biochar @ 4 t ha-1. Significantly, the lowest value in grain (2.45 %), stover (0.81 %) and total (3.26 %) were recorded in absolute control.

The application of nitrogen and biochar resulted in higher nitrogen content at harvest in RDF applied treatments than RDF not applied treatments and control. Among the different treatments, 100 % RDF + biochar @ 4 t ha^{-1} has recorded the highest N concentration. As urea was not applied in control, the lowest plant nitrogen content was noticed due to less supply of nitrogen. Further soil was initially low in available nitrogen (198.10 kg ha^{-1}).

Biochar can enhance biological nitrogen fixation by stimulating nodulation on roots with adsorption of flavonoids and nod factors which lead to an increase in nitrogen fixation by roots and its availability to shoots. Increase in nitrogen content in both grains and straw of chickpea with biochar addition was also supported by Budania and Janardhan (2014) and Thies *and* Rilling, (2009).

Phosphorus concentration in chickpea (%): The concentration of phosphorus in both grains and stover of chickpea was influenced significantly with different levels of biochar. The significantly highest phosphorus concentration in grain (0.51 %), stover (0.30 %) and total (0.81 %) was found in treatment which received 100 % RDF + biochar @ 4 t ha^{-1} followed by (0.50, 0.29 and 0.79 % in grain, stover and total respectively), which received 100 % RDF + biochar @ 2 t ha^{-1} and (0.49, 0.28 and 0.77 % in grain, stover and total) respectively, which received 50 % RDF + biochar @ 4 t ha^{-1} which found on par with the application of 100 % RDF + biochar @ 4 t ha^{-1}. Significantly, lowest value (0.25, 0.18 and 0.43 % in grain, stover and total respectively), was noticed in absolute control, that did not received any external nutrient and biochar sources.

Among the different treatments, application of biochar has significantly influenced phosphorous concentration in chickpea plant when compared to biochar untreated plots. In the present investigation, 100 % RDF + biochar @ 4 t ha^{-1} recorded the highest phosphorus concentration in chickpea. Biochar application leads to increase in the availability of phosphorus by reducing its fixation with the formation of phosphor humic complex which increased its absorption by the plant tissues. Significant increase in phosphorus content with the application of biochar was also supported by Nguyen *et al*., 2012 and Agegnehu *et al*. (2015).

Potassium content (%): The data presented in table showed significant influence on potassium contents with the application of biochar along with inorganic fertilizers compared to absolute control. The potassium content in both grains and stover after the harvest of the chickpea crop was significantly higher 1.31, 1.69 and 3.00 % for grains, stover and total, respectively 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} with grain (1.28 %), stover (1.62 %) and total (2.90 %) and treatment with receiving of 50 % RDF + biochar @ 4 t ha-1 in grain (1.27 %), stover (1.61 %) and total (2.88 %). Significantly, the lowest was recorded in absolute control (0.96, 1.30 and 2.26 % in seed, stover and total, respectively).

At harvest stage, highest potassium concentration was observed in stover than in seed in all the treatments. This might be attributed to the biochar application, which acted as the storehouse of both macro and micronutrients and was released during the mineralization cycle. In the present investigation, 100 % RDF + biochar @ 4 t ha^{-1} recorded the highest potassium concentration in chickpea. In addition to extracting nutrients from the organic matter, the organic acids produced through the cycle of decomposition solubilize the native nutrients from the soil and thus improve the plant supply.

Evangelou *et al*., 2014 also found that, application of biochar significantly increased potassium content in plant shoots. Addition of biochar leads to significant increase in concentration of potassium in the plant tissues due to higher ash content of the biochar (Yusof *et al*., 2015) that contained 1.52 per cent K. Lehmann *et al*. (2006), recorded similar results. Application of biochar generated at a temperature of 400 ° C and with a low C: N ratio leads to improved soil productivity and is expressed in further straw and grain uptake. Increased assimilation of N that increased root growth also improved the concentration and uptake of other two major nutrients. (Chamorro *et al*., 2002).

3.2 Micronutrients Concentration in Chickpea (Fe, Mn, Zn and Cu)

The data on micronutrients concentration like Fe, Mn, Zn and Cu in chickpea are presented in Fig. 1.

3.2.1 Iron concentration in chickpea (mg kg^{-1})

The concentration of iron in chickpea plant did not varied significantly between treatments. Even though numerically higher iron concentration of 169.59, 39.69 and 209.28 mg kg^{-1} for grain, stover and total, respectively were recorded with the application of 100 % RDF + biochar @ 4 t ha^{-1}, never the less, a lower concentration values of 130.83, 21.76 and 152.27 mg kg^{-1} in grain and stover respectively were found in absolute control, which was not provided with no external nutrient supply and biochar.

3.2.2 Zinc concentration in chickpea (mg kg^{-1})

The concentration of zinc in plant differed significantly among the treatments with increasing rate of biochar in combination with fertilizers. Significantly higher zinc concentration (35.69, 12.36 and 48.05 mg kg^{-1} in grain, stover and total, respectively) was recorded with the application of 100 % RDF + biochar @ 4 t ha^{-1}. However, it was on par with 100 % RDF + biochar @ 2 t ha^{-1} (34.56, 11.82 and 46.38 mg kg^{-1} in grain, stover and total, respectively) and with 50 % RDF + Biochar @ 4 t ha^{-1} (34.22, 11.69 and 45.90 mg kg^{-1} in grain, stover and total, respectively). The lower zinc concentration was recorded in absolute control (27.30, 7.58 and 34.88 mg kg^{-1} in grain, stover and total, respectively) which had not received any external supply of nutrients and biochar.

3.2.3 Manganese concentration in chickpea plant (mg kg^{-1})

The concentration of manganese in chickpea plant did not differ significantly among the treatments with increasing rate of biochar application. Numerically higher Manganese concentration (41.46, 15.41 and 56.87 mg kg-1 in grain, stover and total, respectively) was found with the application of 100 % RDF + biochar @ 4 t ha-1 followed by 100 % RDF + biochar @ 2 t ha-1 (40.15, 14.72 and 54.87 mg kg-1 in grain, stover and total, respectively). However, a lower value of 22.79, 10.13 and 32.92 mg kg-1 manganese concentration in grain, stover and total, respectively was noticed in absolute control.

3.2.4 Copper concentration in chickpea plant (mg kg^{-1})

The concentration of copper in chickpea plant did not differ significantly among the treatments with increasing rate of biochar application. Numerically higher copper concentration (11.38, 12.87 and 24.25 mg kg-1 in grain, stover and total, respectively) was found with the application of 100 % RDF + biochar @ 4 t ha-1 followed by

100 % RDF + biochar @ 2 t ha-1 (11.24, 12.39 and 23.63 mg kg-1 in grain, stover and total, respectively) when compared to 100 % RDF with no application of biochar (9.53, 8.65 and 18.18 mg kg-1 in grain, stover and total, respectively). However, a lower value of 7.74, 6.63 and 14.37 mg kg-1 Copper concentration in seed, stover and total, respectively was noticed in absolute control.

4. EFFECT OF BIOCHAR ON NUTRIENT UPTAKE OF MAJOR AND MICRONUTRIENTS BY GRAIN, STOVER AND TOTAL UPTAKE OF CHICKPEA

4.1 Major Nutrients (N, P and K) Uptake by Chickpea

The uptake of N, P and K by grain, stover and total uptake of chickpea are presented in Fig. 2, 3 and 4.

4.1.1 Nitrogen uptake (kg ha^{-1}) by chickpea

The perusal of data presented in Fig. 2, 3 and 4 showed that uptake of nitrogen by chickpea plant was significantly influenced by the different levels of biochar application. Significantly higher nitrogen uptake (52.01, 22.10 and 74.11 kg ha-1 by grain, stover and total, respectively) 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 (48.85, 21.20 and 70.05 kg ha-1 in grain, stover and total, respectively) and treatment which received 50 % RDF + biochar @ 4 t ha-1 (47.55, 20.81 and 68.36 kg ha-1 by grain, stover and total, respectively) when compared to 100 % RDF without biochar supply (39.96, 17.08 and 57.04 kg ha-1 by grain, stover and total, respectively). Significantly, the lower nitrogen uptake (26.03, 11.53 and 37.56 kg ha-1 by grain, stover and total, respectively) was found in absolute control which received no external nutrient and biochar supply.

The reason for higher uptake of nitrogen under high doses of biochar might be due to the positive effects of biochar on crop growth, along with positive effects of crop plant uptake on nutrients (P and K) and soil availability of P, K, Ca and Mg. The uptake of nutrients is a feature of the nutrient concentration and the dry matter yield. Increased biochar application rate increased the production of dry matter which obviously increased the nutrient uptake. Chan *et al*. (2007) and Zhao *et al*. (2014) noted a rise in N uptake at higher biochar levels. Angst and Sohi (2013) and Yao *et al*. (2013) reported that, primary nutrients availability and plant uptake increased the response to biochar application, especially when combined with chemical fertilizers.

Deluca and Mackenzie, (2009) stated that, biochar added with an organic N source to the soil yielded an increase in net nitrification and improved plant availability of nitrogen. Laxman Rao *et al*. (2017) also supported the improvement in nitrogen uptake with the biochar addition which was due to multiplication effect of higher nitrogen absorption as well as high biomass production.

4.1.2 Phosphorus uptake (kg ha^{-1}) by chickpea

The uptake of phosphorus of by chickpea grain and stover was significantly influenced by the different levels of biochar application. Significantly higher phosphorus uptake (7.32, 5.26 and 12.58 kg ha-1 by grain, stover and total, respectively) was noticed with the application of 100 % RDF + biochar @ 4 t ha-1. However, it was on par with the application of 100 % RDF + biochar @ 2 t ha- 1 (7.07, 5.12 and 12.19 kg ha-1 grain, stover and total, respectively) and treatment which received 50 % RDF + biochar @ 4 t ha-1 (6.81, 4.97 and 11.78 kg ha-1 by grain, stover and total, respectively) when compared to 100 % RDF without biochar application (4.92, 3.93 and 8.85 kg ha-1 in grain, stover and total, respectively). Significantly, lower uptake (2.68, 2.57 and 5.25 kg ha-1 in grain, stover and total, respectively) was reported in absolute control where no external nutrient and biochar source was applied. There was a significant difference in phosphorus uptake by chickpea due to biochar application in combination with fertilizers.

All the inorganic phosphorus applied treatments recorded significantly higher phosphorus uptake due to high biomass production. In the present investigation, 100 % RDF + Biochar @ 4 t ha-1 recorded higher phosphorous uptake. The priming effects, competitive sorption processes or improvement in root growth might have contributed to the increased P recovery and its uptake by the plant. Agegnehu *et al*. (2015) noticed that, higher phosphorus uptake by the plant indicated that, biochar treated soil maintained higher concentration of these nutrients in the soil solution due to reduced leaching.

Applied biochar forms phosphor humic complex it solubilizes and reduce P fixation, this improves P uptake. Significant increase in phosphorus uptake with the biochar addition was also supported by Supriyadi *et al*. (2012). Aziz *et al*. (2006) indicated that the increased availability of P can also be induced healthy root development by reduced Al toxicity which causes root damage. Similarly, with the introduction of biochar, Uzoma *et al*. (2011) and Yamato *et al*. (2006) recorded an improvement of the available plant P in soil.

4.1.3 Potassium uptake (kg ha-1) by chickpea

The data presented in Table 2 and Fig. 2 states that, uptake of potassium by chickpea was significantly influenced with increased level of biochar application when applied in combination with fertilizers. Significantly higher K uptake (18.80, 29.88 and 48.68 kg ha-1 by grain, stover and total, respectively) was reported 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 (18.15, 28.62 and 46.77 kg ha-1 in grain, stover and total, respectively) and the treatment which received 50 % RDF + biochar @ 4 t ha-1 (17.82, 28.14 and 45.96 kg ha-1 by grain, stover and total, respectively) when compared to 100 % RDF and without application of biochar (15.63, 24.25 and 39.88 kg ha-1 by grain, stover and total, respectively). Significantly, lowest uptake (10.24, 18.46 and 28.7 kg ha-1 by grain, stover and total, respectively) was reported in absolute control where no external nutrient and biochar was applied.

The increase in K concentration and uptake might be due to biochar ash content which helps to release occluded K for crop use immediately. Most of the uptake of nutrients (N and K) will increase as the biochar influenced the increased availability of water due to greater surface area. In addition, biochar has the capacity to increase the soil's CEC, thereby increasing the soil's ability to hold K and make it available for plant uptake. In the present investigation, 100 % RDF + biochar @ 4 t ha-1 recorded the higher potassium concentration. The availability of K increased as the soil pH increased by applying biochar in combination with agricultural lime (Manolikaki and Diamadopoulos, 2016), Rondon *et al*. (2007) also reported increased K uptake by plant biomass. Higher cation exchange capacity of biochar decreased the losses of potassium and thus increased its uptake. When biochar was added to the soil, it’s surface oxidation by biotic and abiotic agents resulted in development of negative charges that give ability to biochar to sorb more cations like potassium which lead to increase in uptake of nutrients (Danish *et al*., 2014). Abrishamkesh *et al*. (2015) also noticed that, high ash content in biochar amended soils could be attributed to high ash content of biochar and immediate release of potassium from the ash could result in higher uptake of potassium by the plant.

4.2 Micronutrients (Fe, Mn, Zn, and Cu) Uptake by Chickpea

4.2.1 Iron uptake (g ha-1) by chickpea

The perusal of data presented in Table 2 showed that, uptake of iron by chickpea crop was significantly influenced by the different levels of biochar application. Significantly higher value of iron uptake (243.40, 70.15 and 313.55 g ha-1 by grain, stover and total, respectively) was recorded with 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 (231.07, 67.55 and 298.62 g ha-1 by grain, stover and total, respectively) and with the application of 50 % RDF + biochar @ 4 t ha-1 (224.59, 65.25 and 289.84 g ha-1 by grain, stover and total, respectively when compared to the treatment which received 100 % RDF and without application of biochar (187.77, 51.30 and 239.07 g ha-1 by grain, stover and total, respectively). Significantly, the lower uptake (137.49, 30.88 and 168.37 g ha-1 by grain, stover and total, respectively) was reported in absolute control where no external nutrients and biochar was applied.

4.2.2 Zinc uptake (g ha-1) by chickpea

The data presented in Table 2 states that, uptake of zinc by chickpea was significantly influenced due to different levels of biochar application when applied in combination with chemical fertilizers.

Significantly higher zinc uptake (51.23, 21.85 and 73.08 g ha-1 by grain, stover and total, respectively) was reported with the application of 100 % RDF + biochar @ 4 t ha-1. However, it was found to be par with the application of 100 % RDF + biochar @ 2 t ha-1 (48.94, 20.88 and 69.82 g ha-1 by grain, stover and total,

Table 1. Major nutrients concentration in chickpea as influenced by application of biochar

Treatments	Nitrogen (%)			Phosphorous(%)			Potassium(%)		
	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total
T_1-Absolutecontrol	2.45	0.81	3.26	0.25	0.18	0.43	0.96	1.30	2.26
T_2-RDFonly(25:50:00)	3.01	1.00	4.01	0.37	0.23	0.60	1.18	1.42	2.60
T_3-Biochar@2tha^{-1}	2.75	0.89	3.64	0.29	0.20	0.49	1.05	1.31	2.36
T_4-Biochar@4tha^{-1}	2.90	0.94	3.84	0.32	0.21	0.53	1.08	1.36	2.44
T_5-50%RDF+Biochar@2tha^{-1}	3.19	1.05	4.24	0.40	0.24	0.64	1.19	1.50	2.69
T_6-50%RDF+Biochar@4tha^{-1}	3.40	1.19	4.59	0.49	0.28	0.77	1.27	1.61	2.88
T_7-100%RDF+Biochar@2tha^{-1}	3.45	1.20	4.65	0.50	0.29	0.79	1.28	1.62	2.90
T_8-100%RDF+Biochar@4tha^{-1}	3.62	1.25	4.87	0.51	0.30	0.81	1.31	1.69	3.00
S.Em.±	**0.07**	**0.02**	**0.07**	**0.01**	**0.01**	**0.01**	**0.02**	**0.03**	**0.03**
CD @5%	**0.23**	**0.07**	**0.22**	**0.03**	**0.02**	**0.03**	**0.05**	**0.10**	**0.10**

Legend:RDF- Recommendeddoseof fertilizer
Farm yard manure @ 5 t ha^{-1}is common for all the treatments except T_1.
Zincsulphate (21%)@5kgha^{-1} is common for all the treatments except T_1

Table 2. Micronutrients uptake in chickpea as influenced by the application of biochar

Treatments	Iron (g ha^{-1})			Zinc(g ha^{-1})			Manganese (g ha^{-1})			Copper(g ha^{-1})		
	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total
T_1-Absolutecontrol	137.49	30.88	168.37	29.45	10.77	40.22	23.92	14.46	38.38	8.40	9.46	17.86
T_2-RDFonly(25:50:00)	187.77	51.30	239.07	40.48	16.66	57.14	44.86	20.45	65.31	12.66	14.74	27.40
T_3-Biochar@2tha^{-1}	159.32	35.77	195.09	33.00	12.40	45.40	31.76	16.07	47.83	10.02	11.35	21.37
T_4-Biochar@4tha^{-1}	171.79	44.17	215.96	36.10	14.19	50.29	37.26	17.87	55.13	11.27	13.15	24.42
T_5-50%RDF+Biochar@2tha^{-1}	203.08	55.50	258.58	44.18	17.83	62.01	48.61	21.62	70.23	13.53	16.15	29.68
T_6-50%RDF+Biochar@4tha^{-1}	224.59	65.25	289.84	47.83	20.48	68.31	55.79	25.41	81.20	15.39	21.47	36.86
T_7-100%RDF+Biochar@2tha^{-1}	231.07	67.55	298.62	48.94	20.88	69.82	57.56	26.01	83.57	15.85	21.91	37.76
T_8-100%RDF+Biochar@4tha^{-1}	243.40	70.15	313.55	51.23	21.85	73.08	59.46	27.25	86.71	16.31	22.75	39.06
S.Em.±	**17.93**	**7.71**	**15.25**	**1.43**	**0.50**	**1.25**	**6.26**	**2.81**	**6.16**	**1.04**	**3.00**	**2.98**
CD @5%	**54.38**	**23.38**	**46.25**	**4.33**	**1.51**	**3.78**	**19.00**	**8.51**	**18.70**	**3.17**	**9.09**	**9.03**

Legend: RDF-Recommended dose of fertilizer
Farm yard manure@5 t ha^{-1}is common for all the treatments except T_1 Zinc sulphate (21%)@5kgha^{-1} is common for all the treatments except T_1

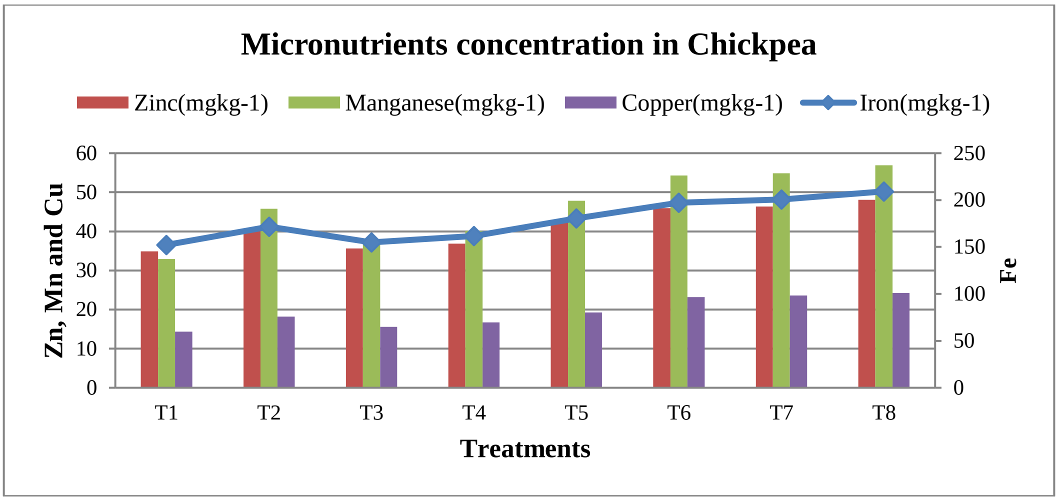

Fig. 1. Micronutrients concentration chickpea after harvest as influenced by application of biochar

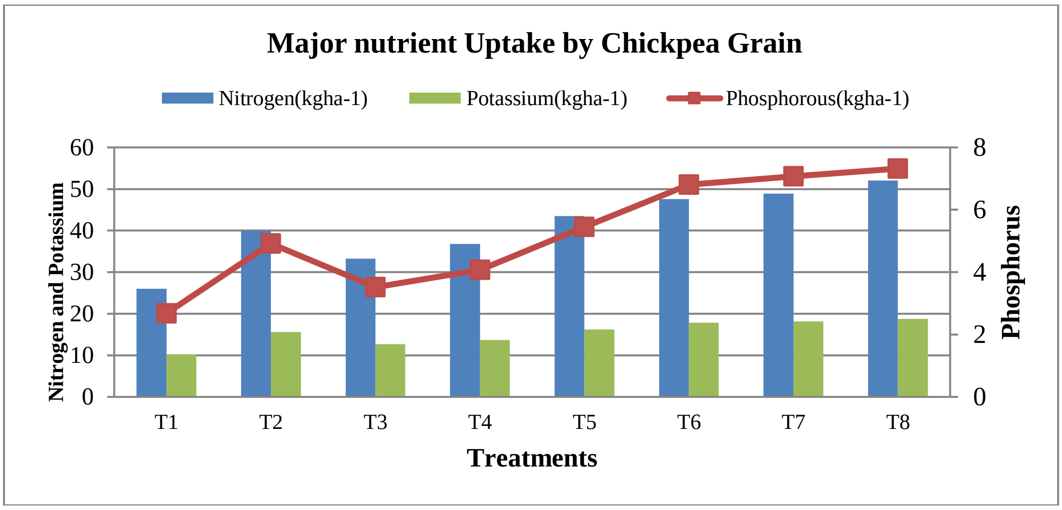

Fig. 2. Nutrient uptake by chickpea Grain after harvest as influenced by application of biochar

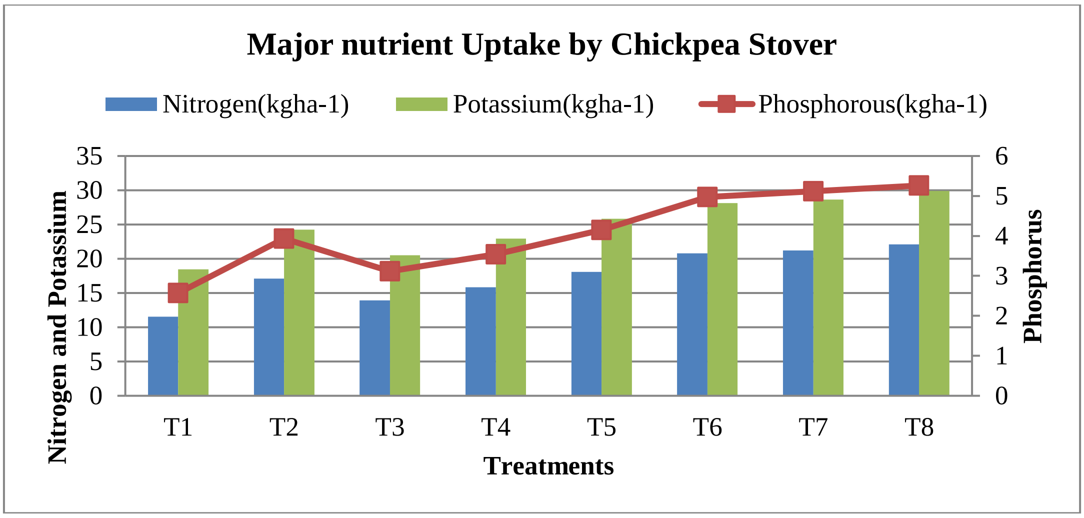

Fig. 3. Nutrient uptake by chickpea Grain after harvest as influenced by application of biochar

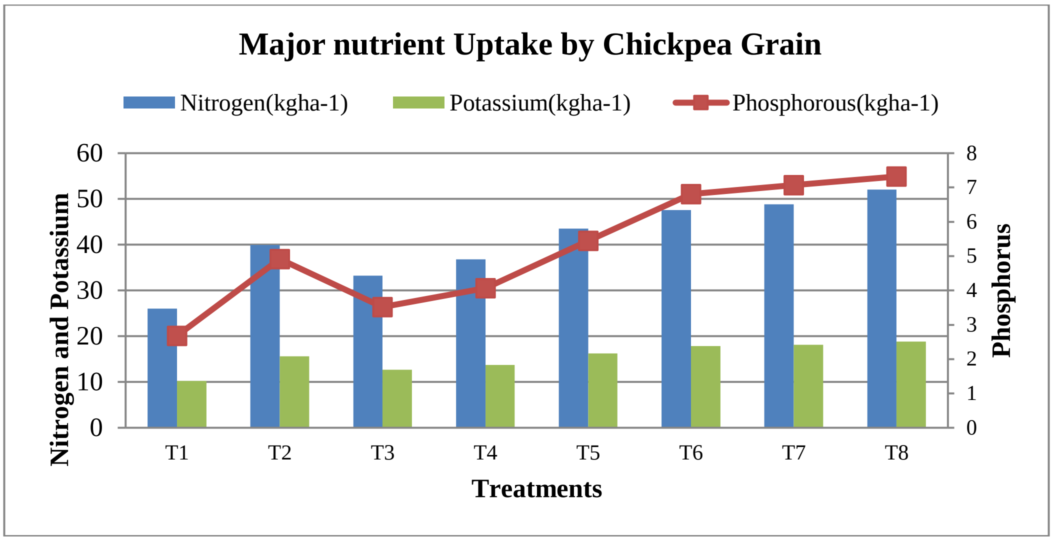

Fig. 4. Nutrient uptake by chickpea Grain after harvest as influenced by application of biochar

respectively) and with the application of 50 % RDF + biochar @ 4 t ha-1 (47.83, 20.48 and 68.31 g ha-1 by grain, stover and total, respectively) when compared to the treatment which received only 100 % RDF without application of biochar (40.48, 16.66 and 57.14 g ha-1 by grain, stover and total, respectively). Significantly, the lower uptake (29.45, 10.77 and 40.22 g ha-1 in grain, stover and total, respectively) was reported in absolute control which had no external supply of nutrients and biochar were applied.

4.2.3 Manganese uptake (g ha-1) by chickpea

The data presented in Table 2 showed that, uptake of manganese by chickpea was significantly influenced by the different levels of biochar application. Significantly higher uptake of manganese (59.46, 27.25 and 86.71 g ha-1 by grain, stover and total, respectively) was reported 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 (57.56, 26.01 and 83.57 g ha-1 by grain, stover and total, respectively) and 50 % RDF + biochar @ 4 t ha-1 (55.79, 25.41 and 81.20 g ha-1 by grain, stover and total, respectively). Significantly lower uptake (23.92, 14.46 and 38.38 g ha-1 by grain, stover and total, respectively) was reported in absolute control where no external nutrients and biochar source was applied.

4.2.4 Copper uptake (g ha-1) by chickpea

Table 2 showed that, uptake of copper by seed and stover of chickpea, was significantly influenced by the different rates of biochar application with the combination of chemical fertilizers.

Significantly higher copper uptake (16.31, 22.75 and 39.06 g ha-1 by grain, stover and total, respectively) was reported with the application of 100 % RDF + biochar @ 4 t ha-1 followed by 100 % RDF + biochar @ 2 t ha-1 (15.85, 21.91 and 37.76 g ha-1 by grain, stover and total, respectively) and 50 % RDF + biochar @ 4 t ha-1 (15.39, 21.47 and 36.86 g ha-1 by grain, stover and total, respectively) when compared to the treatment with the application of only 100 % RDF with no biochar supply (12.66, 14.74 and 27.40 g ha-1 in grain, stover and total, respectively). Significantly lower absorption (8.40, 9.46 and 17.86 g ha-1 in grain, stover and total, respectively) was recorded in absolute control with no external supply of nutrients and biochar.

5. CONCLUSION

The total uptake of micronutrients *viz*., Fe, Zn, Mn and Cu by chickpea varied significantly due to biochar application. Higher total uptake of Fe, Zn, Mn and Cu by chickpea was recorded in the treatment with the application of 100 % RDF + Biochar @ 4 t ha-1 and the lower uptake was recorded in absolute control where no external source of nutrients and biochar were applied. Higher uptake of these micronutrients was due to higher dry matter yield along with higher doses of biochar application. Application ofbiochar is accompanied by increase in soil pH and reduced mobility of micronutrients. But in presence of plant, which actively releases organic acids in rhizosphere may mobilize the native micronutrients. Lehmann *et al*. (2003) noticed higher uptake of Zn and Cu by the plants with increased levels of biochar due to reduced leaching losses and increased fertilizer use efficiency. Similar fin dings were also reported by Antonio *et al*. (2013) and Willis *et al*. (2016).

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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