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Residual effects of biochar on soil properties and yield of chickpea grown after maize in a Vertisol

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ABSTRACT

The present investigation was undertaken during 2020-21 at the Research Farm of the Department of Agronomy, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola (M.S.). The experiment was laid out in Randomized Block Design (RBD) with eight treatments and three replications. The objectives were to study the residual effect of biochar on soil properties and yield of chickpea as well as its residual effect on carbon stock in the soil. The results revealed that the grain yield of chickpea significantly increased due to the application of 100% RDN with the Biochar @ 5 t ha^{-1} applied in the Kharif season. Whereas, soil physical properties viz. bulk density decreased with the application of 100% RDN, yet effects were non-significant. The water holding capacity of the soil significantly increased with the application of 100% RDN with Biochar @ 5 t ha^{-1} applied in the Kharif season. Similarly, soil organic carbon, SOC stock as well as available nitrogen (N), phosphorus (P), and potassium (K), after harvesting of chickpea, significantly increased due to the application of 100% RDN. Proper plant nutrition is an important factor in improving the yield and quality of chickpea. From this study, it can be concluded that soil application of 100% RDN + Biochar 5 t ha^{-1} for Kharif maize and 75% RDN for rabi chickpea favorably influenced the physical and chemical properties of soil and chickpea yield. A slight improvement in soil fertility status was also noted.

Keywords: Biochar, Residual effect, Chickpea, Yield, Soil properties, Vertisol

INTRODUCTION

Biochar is a carbon-rich, fine-grained, a porous substance produced under oxygen limiting conditions at a temperature between 350 to 700 ^{0}C. It can be defined as the solid residue obtained from the thermochemical decomposition or pyrolysis of plant and waste feedstocks and can be specifically used for application to the soil as part of an agronomic or environmental management plan (Lehmann *et. al.,* 2009). It is not a pure carbon but rather a mix of Carbon (C), Hydrogen (H), Oxygen (O), Nitrogen (N), Sulphur (S), and ash in different proportions (Raveendran *et al.,*1995; Skodras *et al.,* 2006; Bourke *et al.,* 2007). It is also known as the "Black Gold" of agriculture. Agricultural crop residues form a major source of biomass in India annually about 500 million tonnes yr^{-1}. The chemical composition of the biochar includes approximately organic 38.8% carbon, 1 g kg^{-1} Total P_2O_5, 3.3 g kg^{-1} K_2O, 5.7 g kg^{-1} $CaCO_3$, 1.1 g kg^{-1} MgO, and 68.2 C: N (Yeboah, 2009). Apart from carbon sequestration, other environmental benefits can be derived from the application of biochar in soils which include a reduction in the emission of non-CO_2 GHGs by soils. Biochar is resistant to microbial degradation; therefore soil quality, nutrient cycling, and carbon sequestration through its application to agricultural land have received rising consideration. The residual effect of biochar considerably improves soil water holding capacity, soil Cation Exchange Capacity (CEC), and nutrient retention especially in soils deficient in organic matter content or soil having less microbial activities. It can improve chickpea-rhizobium symbiotic performance and soil biological activity. Concerning the residual effect of biochar on soil properties the bulk density decreases whereas there is an increase in organic carbon content in the soil. Application of biochar to previous crops also improves yield and yield parameters of the next crop as well as different soil properties. Thus, legumes must be involved in the cropping system for sustained productivity and improved soil properties.

Chickpea (*Cicer arientinum* L.) is an important pulse crop grown and consumed all over the world, especially in the Afro-Asian countries. Among pulses chickpea rank third in the world. In India, the total area under chickpea was 8.56 million hectares with the production of 7.35 million tones with average productivity of 858 kg ha^{-1}. In Maharashtra, in 2015, the area under chickpea cultivation was 13.13 lakh hectares with a production of 42.46 lakh tonnes with average productivity of 935 kg ha^{-1} (www. Sopa.com). India ranks first in the world in production as well as acreages followed by Pakistan. The largest chickpea producing states in India in terms of area are Madhya Pradesh, Andhra Pradesh, Rajasthan, Haryana, and Karnataka. In Maharashtra chickpea rank second, next to pigeon pea crop in the production as well as productivity. Among leguminous crops, chickpea occupies an important position due to its nutritional value. It contains 17-23% proteins, 14% vitamins, 24-41% raw starch, 50-64% carbohydrates, 3-7% fats, 3.7-13% crude fiber and 6% oil. It is also a good source of Vitamin A and other B vitamins like thiamine, riboflavin, niacin, and pantothenic acid. It also contains some minerals like Ca- 68 mg 100^{-1} g, Mg- 107 mg, P- 169 mg, and Fe- 3 to 12 mg.

MATERIAL AND METHODS

The field experiment was conducted during the rabi season of 2020-21 at the Research farm of the Department of Agronomy, Dr. PD Krishi Vishwavidyalaya, Akola to study the Residual effect of biochar on the yield of chickpea and soil properties grown after maize. The present study consist of nine treatments replicated three times with chickpea as a test crop. The treatments comprised of T_1- Control, T_2- 100% RDN, T_3- 75% RDN + Biochar 2.5 t ha^{-1}, T_4-100% RDN + Biochar 2.5 t ha^{-1}, T_5- 125% RDN + Biochar 2.5 t ha^{-1}, T_6- 75% RDN + Biochar 5 t ha^{-1}, T_7- 100% RDN + Biochar 5 t ha^{-1} and T_8- 125% RDN + Biochar 5 t ha^{-1} for Kharif maize and treatments T_1- Control, T_2- 100% RDN, T_3- 50% RDN, T_4- 75% RDN, T_5- 100% RDN, T_6- 50% RDN, T_7- 75% RDN and T_8- 100% RDN for rabi chickpea. The recommended dose of fertilizer (RDF) was 25:50:30 NPK kg ha^{-1}. Nitrogen through urea was applied at the time of sowing. The various soil properties were analyzed following the standard method. The grain and straw yield of chickpea was recorded and expressed in appropriate units. The treatments comprised of unfertilized control, chemical fertilizer alone, and their combinations with different doses of biochar. The soil of the experimental site was medium black belonging to Vertisol and alkaline in reaction. The soil and plant samples were collected and analyzed for their different properties. The data were subjected to statistical analysis as per Gomez and Gomez (1984). The initial status of the soil of the experimental site was classified as vertisol and moderately alkaline in reaction (7.72), non-saline (0.27 dS m^{-1}), medium in organic carbon (5.7g kg^{-1}), calcareous (10.25%), low in available nitrogen (221.02 kg ha^{-1}), low in available phosphorus (15.46 kg ha^{-1}) and high in available potassium (339 kg ha^{-1}).

Biochar: The biochar prepared from different crop residues available on-farm was alkaline with pH of 8.7 and EC of 0.60 dS m^{-1}, had a total organic carbon content of 74.14%, and total nitrogen, phosphorous, and potassium content of 0.471%, 0.227%, and 1.26%, respectively. It had C:N ratio of 157.40%. Similar properties of biochar have been reported by Pandian *et al.* (2016).

RESULTS AND DISCUSSION

Yield of chickpea

Significantly higher grain (19.39 q ha^{-1}) and straw (17.84 q ha^{-1}) yield of chickpea (Table 1) were found with the application of 100% RDN (Biochar 5 t ha^{-1} in Kharif season) and was at par with the treatments T_7, T_5 and T_2 (Table 1). Increased grain and straw yield of chickpea under the residual effect of biochar may be due to better partitioning and migration of the total available photosynthates to economic yield (Shaleh *et al.* 2011). Application of N, P, and K fertilizers with biochar gave higher availability of nutrients compared with no biochar application. This was one of the reasons for higher grain yield in the second season than that in the first season. Similar results were obtained by Steiner *et al.* (2007) and Kimetu *et al.* (2008).

Table 1. The yield of chickpea as influenced by various treatments

	Treatments		Yield of chickpea (q ha^{-1})	
	Kharif Maize	Rabi Chickpea	Grain	Straw
T1	Control	Control	09.66	08.41
T2	100% RDN	100 % RDN	18.51	17.10
T3	75%RDN + Biochar 2.5 t ha^{-1}	50 % RDN	14.08	13.36
T4	100% RDN + Biochar 2.5 t ha^{-1}	75 % RDN	16.10	15.70
T5	125% RDN + Biochar 2.5 t ha^{-1}	100 % RDN	18.78	17.60
T6	75% RDN + Biochar 5.0 t ha^{-1}	50 % RDN	15.31	14.55
T7	100% RDN + Biochar 5.0 t ha^{-1}	75 % RDN	18.61	16.64
T8	125% RDN + Biochar 5.0 t ha^{-1}	100 % RDN	19.39	17.84
	S.E.(m)±		0.64	0.43
	C.D.at 5%		1.94	1.30

Physical properties

The data regarding physical properties of soil i.e., bulk density and water holding capacity before and after harvesting of chickpea is presented in Table 2. Bulk density of soil after harvesting chickpea was found to be reduced as compared to after harvest of maize. The highest bulk density (1.56 Mg m^{-3}) was observed in treatment control (T_1) and the lowest bulk density (1.52 Mg m^{-3}) was observed in treatment T_8 with the application of 100% RDN and it was found statistically non-significant. Biochar is very porous and could improve soil aeration, thus may reduce the bulk density. Similar results were stated by Busscher *et al.* (2011) and Laird *et al.* (2010). The water holding capacity of soil after harvesting chickpea was significantly increased by various treatments. Higher water holding capacity (57.34%) of soil was observed in treatment T_8 i.e., application of 100% RDN, and it was found to be at par with all the treatments except T_1 and T_2 due to the application of biochar to the soil improves a wide range of physical properties of the soil such as total porosity, moisture content, saturation percentage, water holding capacity and hydraulic conductivity (Atkinson *et al.,* 2010 and Major *et al.,* 2009). Similar results have been reported by Hafeez Ur Rahim *et al.* (2018) and Downie *et al.* (2009).

Chemical properties

The effect of Biochar on soil PH, Electrical conductivity (EC), and Organic Carbon is presented in Table 3. The soil pH ranges from 7.64 to 7.71 and was found statistically non-significant. The higher value of pH (7.71) was recorded in treatment T_1 i.e., in control, while the lowest value of pH (7.64) was recorded in treatment T_8 having 100% RDN. The partial decomposition of biochar can produce organic acids, oxidation or reduction of sulfur as well as the addition of nitrogenous fertilizers especially the ammoniacal form of N release acid upon nitrification process, etc., contribute to a gradual decrease in soil pH. Similar results were also observed by Shenbagavalli and Mahimairaja (2012). Soil EC ranges from 0.26 to 0.31 dS m^{-1} and was found statistically non-significant. The highest EC (0.31dS m^{-1}) was recorded in treatment T_8 having 100% RDN and the lowest one (0.26 dS m^{-1}) was recorded in treatment T_1 i.e., control. The EC of the

Table 2. The residual effect of biochar on soil physical properties

	Treatments		Bulk Density	Water Holding
	Kharif Maize	Rabi Chickpea	(Mg m^{-3})	Capacity (%)
T1	Control	Control	1.56	48.28
T2	100% RDN	100 % RDN	1.55	49.66
T3	75%RDN + Biochar 2.5 t ha^{-1}	50 % RDN	1.55	51.23
T4	100% RDN + Biochar 2.5 t ha^{-1}	75 % RDN	1.54	53.66
T5	125% RDN + Biochar 2.5 t ha^{-1}	100 % RDN	1.54	55.22
T6	75% RDN + Biochar 5.0 t ha^{-1}	50 % RDN	1.53	54.16
T7	100% RDN + Biochar 5.0 t ha^{-1}	75 % RDN	1.53	56.21
T8	125% RDN + Biochar 5.0 t ha^{-1}	100 % RDN	1.52	57.34
	S.E.(m)±		0.01	2.10
	C.D.at 5%		-	6.28

Table 3. The residual effect of biochar on soil chemical properties

	Treatments		pH	EC	OC
	Maize	Chickpea		(dS m^{-1})	(g kg^{-1})
T1	Control	Control	7.71	0.26	5.89
T2	100% RDN	100 % RDN	7.69	0.27	6.11
T3	75%RDN +Biochar 2.5 t ha^{-1}	50 % RDN	7.68	0.27	6.20
T4	100% RDN +Biochar 2.5 t ha^{-1}	75 % RDN	7.67	0.28	6.29
T5	125% RDN +Biochar 2.5 t ha^{-1}	100 % RDN	7.66	0.27	6.32
T6	75% RDN +Biochar 5.0 t ha^{-1}	50 % RDN	7.65	0.29	6.38
T7	100% RDN +Biochar 5.0 t ha^{-1}	75 % RDN	7.65	0.30	6.47
T8	125% RDN +Biochar 5.0 t ha^{-1}	100 % RDN	7.64	0.31	6.53
	S.E.(m)±		0.04	0.012	0.09
	C.D.at 5%		-	-	0.28

soil generally increased with the application of biochar due to the release of weakly bonded nutrients (cations and anions) into the soil solution, which are also accessible to plants for uptake (Sara *et al.,* 2018). Similar results have been observed by Gundale *et al.* (2007) and Nigussie *et al.* (2012).

Significantly highest soil organic carbon (6.53 g kg^{-1}) was recorded in treatment T_8 having 100% RDN and was found statistically at par with all treatments except treatments T_1, T_2, and T_3 and it may be due to high carbon content in biochar resulting in greater accumulation of SOC. Higher values of soil organic carbon were found in biochar treated plots (T_3 to T_8) over non-treated plots (T_1 and T_2), and the application rate of biochar was in direct relation to the increase in organic carbon of soil. The results were in line with the findings of Sukartono *et al.* (2011) and Sara *et al.* (2018).

Available nitrogen

The significantly higher available nitrogen (Table 4) in soil was recorded in treatment T_8 (254.67 kg ha^{-1}) containing 100% RDN over the remaining treatments and was found statistically at par with treatments T_7, T_5, T_4, and T_2 due to residual effect of biochar. It was noted that available nitrogen in the soil after harvesting of chickpea increases as compared to initial samples (249.33 kg ha^{-1}) *i.e.*, after harvesting of maize because of previously applied biochar in Kharif season and its property to retain the nutrients on its high surface area is one of the beneficial effects of biochar. Widowati *et al.* (2012), stated that biochar can reduce nitrogen fertilizer application by up to 70% because biochar can manage nitrogen release by urea fertilizer in the form of NH_4. It has been hypothesized that the long-term effect of biochar on nutrient availability is due to an increase in surface oxidation and CEC (Liang *et al.,* 2006), which intensifies over time and can lead to greater nutrient retention in “aged” as opposed to “fresh” biochar. These findings were in agreement with the findings of Steiner *et al.* (2007) and Sara *et al.* (2018).

Available phosphorus

The available phosphorus (Table 4) in soil was significantly higher in treatment T_8 (23.53 kg ha^{-1}) containing 100% RDN over the remaining treatments and was found statistically at par in treatments T_7, T_6, T_5, T_4, and T_2. This may be due to the complexation of polyvalent metal cations by oxygen-containing surface functional groups or carboxylate groups of biochar that can transform a surface charge site from negative to positive. This can create an anion exchange site and increase phosphorus availability. Biochar can be a potential phosphorus source and some biochar can also adsorb phosphorus efficiently from solutions (Peng *et al.,* 2012; Yao *et al.,* 2013). They suggested that biochar could play a role in retaining phosphorus applied as fertilizer. In contrast to other organic matter in the soil, biochar also appears to be able to strongly adsorb phosphate even though it is an anion (Lehmann *et al.,* 2005).

Available potassium

The significantly higher available potassium (Table 4) in soil was recorded in treatment T_8 (367 kg ha^{-1}) containing 100% RDN over the remaining treatments but at par with all the treatments except treatments T_1 and T_3. Since the biochar was made by pyrolysis process and contained at least 0.3% of ash, its application to soils can increase the availability of potassium (Lehmann and Rondon,

Table 4. The residual effect of biochar on available macro-nutrients

	Treatments		Nitrogen	Phosphorus	Potassium
	Maize	Chickpea	(Kg ha^{-1})	(Kg ha^{-1})	(Kg ha^{-1})
T1	Control	Control	218.67	15.23	327
T2	100% RDN	100 % RDN	243.67	18.66	352
T3	75%RDN +Biochar 2.5 t ha^{-1}	50 % RDN	231.67	16.18	348
T4	100% RDN +Biochar 2.5 t ha^{-1}	75 % RDN	242.33	19.26	354
T5	125% RDN +Biochar 2.5 t ha^{-1}	100 % RDN	247.67	20.34	359
T6	75% RDN +Biochar 5.0 t ha^{-1}	50 % RDN	237.33	17.39	356
T7	100% RDN +Biochar 5.0 t ha^{-1}	75 % RDN	249.00	22.11	361
T8	125% RDN +Biochar 5.0 t ha^{-1}	100 % RDN	254.67	23.53	367
	S.E.(m)±		4.20	2.07	5.99
	C.D.at 5%		12.56	6.20	18.09

2006). Potassium availability was increased the most by biochar application in the year following its application and this likely resulted directly from the considerable amounts of potassium that were added along with biochar from which it is readily leached (Major *et al.,* 2010). Similar results were stated with the findings of Griffin *et al.* (2017), who reported that exchangeable K^+ was slightly higher in plots with biochar, in 3rd year indicating that the influence of biochar fades gradually in the years after application. Adekiya *et al.* (2020) reported that soil chemical properties in 2018 were improved compared to 2017; this was because the biochar increased plant nutrient availability with age in soil due to residual effect.

DTPA extractable micronutrients

The residual effect of biochar on available soil micronutrients i.e., Zn, Cu, Fe, and Mn after harvest of chickpea was found non-significant but the slight improvement was found with increased doses of biochar to previous maize crop is presented in Table 5. The maximum available Zn (0.63 mg kg^{-1}), Cu (2.35 mg kg^{-1}), Fe (4.44 mg kg^{-1}), and Mn (9.49 mg kg^{-1}) were recorded in treatment T_8 with the application of 100% RDN over remaining treatments, while the lowest available micronutrients were found in the control treatment. Similar results were noticed by Sanchez Monedero *et al.* (2004), who reported that the application of biochar could lead to the strong adsorption of Cu to biochar particles as confirmed by the sorption data. Lentz and Ippoliti (2011) also noted that there is an increase in available Mn content with the addition of biochar because biochar act as a source of manganese. Hass *et al.* (2012) reported an increase in Mehlich-3 extractable micronutrients (Cu, Zn, Mn, and Fe) as a result of biochar application.

Soil organic carbon stock

The data of soil organic carbon stock as influenced by different treatments is presented in Table 6. Significantly higher SOC stock (14.88 Mg ha^{-1}) was found in treatment T_8 receiving 100% RDN

Table 5. The residual effect of biochar on soil available micronutrients

	Treatments		Zn	Cu	Fe	Mn
	Maize	Chickpea	(mg kg^{-1})	(mg kg^{-1})	(mg kg^{-1})	(mg kg^{-1})
T1	Control	Control	0.53	2.17	4.23	9.20
T2	100% RDN	100 % RDN	0.57	2.20	4.28	9.27
T3	75%RDN +Biochar 2.5 t ha^{-1}	50 % RDN	0.58	2.24	4.32	9.29
T4	100% RDN +Biochar 2.5 t ha^{-1}	75 % RDN	0.59	2.27	4.35	9.33
T5	125% RDN +Biochar 2.5 t ha^{-1}	100 % RDN	0.61	2.28	4.38	9.37
T6	75% RDN +Biochar 5.0 t ha^{-1}	50 % RDN	0.62	2.32	4.41	9.43
T7	100% RDN +Biochar 5.0 t ha^{-1}	75 % RDN	0.63	2.34	4.42	9.47
T8	125% RDN +Biochar 5.0 t ha^{-1}	100 % RDN	0.63	2.35	4.44	9.49
	S.E.(m)±		0.005	0.04	0.09	0.14
	C.D.at 5%		-	-	-	-

Table 6. The residual effect of biochar on soil organic carbon stock

	Treatments		SOC Stock (Mg ha^{-1})
	Kharif Maize	Rabi Chickpea	Harvest
T1	Control	Control	13.78
T2	100% RDN	100 % RDN	14.20
T3	75%RDN + Biochar 2.5 t ha^{-1}	50 % RDN	14.41
T4	100% RDN + Biochar 2.5 t ha^{-1}	75 % RDN	14.53
T5	125% RDN + Biochar 2.5 t ha^{-1}	100 % RDN	14.59
T6	75% RDN + Biochar 5.0 t ha^{-1}	50 % RDN	14.64
T7	100% RDN + Biochar 5.0 t ha^{-1}	75 % RDN	14.84
T8	125% RDN + Biochar 5.0 t ha^{-1}	100 % RDN	14.88
	S.E.(m)±		0.10
	C.D.at 5%		0.31

over the remaining treatments. This was due to the strong carry-over effect of biochar received in the previous season. This was found significantly at par with treatments T_7 and T_6. Similar results were found by Aller *et al.* (2018) who reported that there was a direct relationship between biochar application rate and increase in SOC content. Adekiya *et al.* (2020), reported that the SOC stock in the second year was improved due to the residual effect of biochar from the first season.

CONCLUSIONS

Soil application of 100% RDN + Biochar 5 t ha^{-1} for Kharif maize and 75% RDN for rabi chickpea favorably influenced the physical and chemical properties of soil, and yield of chickpea. Slight improvements in soil fertility status, particularly the macronutrient content and availability were noted. Improvement in soil physical properties like water holding capacity that are of immense importance in crop production indicate that biochar can be an important amendment for improving the performance of the maize-chickpea cropping system.

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