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Akanksha V Kasadiwar
Department of Soil Science and Agricultural Chemistry, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

GS Laharia
Department of Soil Science and Agricultural Chemistry, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

NR Navghare
Department of Soil Science and Agricultural Chemistry, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

AB Age
Department of Soil Science and Agricultural Chemistry, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

SO Hote
Department of Genetics and Plant Breeding, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

Corresponding Author:
Akanksha V Kasadiwar
Department of Soil Science and Agricultural Chemistry, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

Effect of biochar on soil properties, yield and NUE of maize grown in vertisol

Akanksha V Kasadiwar, GS Laharia, NR Navghare, AB Age and SO Hote

Abstract
The fertility quality of the soil declines when chemical fertilizers are applied in excess. The best strategy to restore its fertility is to use less chemical fertilizer and encourage the use of organic manures, such as FYM, vermicompost, biochar, etc. We explore "Effect of biochar on soil properties and yield of maize grown in vertisol" in a field experiment that was carried out during Kharif, 2021–2022, on the Research Farm, Department of Agronomy, Dr. PDKV, Akola. The experiment was laid out in Randomized Block Design (RBD) with eight treatments and replicated three times. The treatments includes of control, various levels of nitrogen and their combinations with 2.5 and 5.0 t ha^{-1} biochar. On the basis of results obtained, significantly higher grain (48.53 q ha^{-1}) and straw (77.35 q ha^{-1}) yield of maize were recorded with the application of 125% RDN + Biochar 5.0 t ha^{-1}. Soil physical and chemical properties like bulk density (1.51 Mg m^{-3}), water holding capacity (57.35%), organic carbon (6.48 g kg^{-1}), available nitrogen (254.42 kg ha^{-1}), phosphorus (22.65 kg ha^{-1}) and potassium (387 kg ha^{-1}) in soil after harvest of maize were observed significantly higher with the application of 125% RDN + Biochar 5 t ha^{-1}. Whereas there was no significant result of various treatments on electrical conductivity and pH of the soil. Higher application rate of biochar recorded slight increase in micronutrients contain (Zn, Cu, Fe and Mn) but were found non-significant by various treatments in the biochar applied soil. Higher the dose of biochar applied, higher the SOC stock (19.60 Mg ha^{-1}) was recorded. From the present investigation, it can be concluded that, the soil application of 100% RDN + Biochar 5 t ha^{-1} beneficially influenced the yield of maize as well as enhance the soil properties.

Keywords: Biochar, maize, soil properties, nitrogen, soil fertility, carbon

Introduction
Maize (*Zea mays* L.) belongs to grass family Poaceae is one of the most important cereal crop in India as well as in the world. It is also known as corn, makka or makki. The primary center of origin of maize is considered to be the Central America and Mexico. Globally, maize is known as "Queen of cereals" because it has the highest genetic yield potential among the cereals. It is third most important annual cereal of the world after rice and wheat in terms of area and production. Among the maize growing countries India rank 4th in area and 7th in production, representing around 4% of world maize area and 2% of total maize production.

The maize grain contains 10-12% protein, 4% oil, 1.5% fat, 0.5% fiber, 66.2% carbohydrates and 2.75% minerals which includes calcium 10 mg, phosphorous 348 mg, and 2 mg iron. It is also rich in vitamin A, nicotinic acid, riboflavin and vitamin E. Green fodder contains about 5% protein, 4.3% fats, 6% minerals and 52.8% carbohydrates. In India 35% maize produced is used for human consumption, 25% each in poultry feed and cattle and 15% in food processing like corn flakes, pop-corn and other industries mainly starch, dextrose, corn syrup, corn oil etc. Thus, it has attained an important position as an industrial crop. Maize is heavy feeder of nutrients and because of its C_4 nature; it is a very efficient in converting solar energy into dry matter.

Biochar is a fine grained, carbon rich, porous product, largely resistant to decomposition remaining after plant biomass that has been subjected to thermo-chemical conversion process (pyrolysis) at low temperature (350-600 °C) in an environment with little or no oxygen (Amonette and Joseph, 2009) [2]. It is one of the most important organic manure which plays a key role to maintain the nutrient status of soil. It can enhance plant growth by improving soil chemical (nutrient retention and availability) and physical characteristics (bulk density and water holding capacity). Biochar has emerged as an important source of nutrients as that of manures and fertilizers to hold a key role in improvement of crop yield by providing favorable soil (H), oxygen (O), nitrogen (N), sulphur (S) and ash in different proportions (Masek, 2009)

[25]. It contains more than 60% carbon and rich in various nutrients and trace elements essential for plant growth and so it is also known as "Black Gold" of agriculture. The chemical composition of biochar is organic carbon 38.8%, Total P_2O_5 1 g kg^{-1}, K_2O 3.3 g kg^{-1}, $CaCO_3$ 5.7 g kg^{-1}, MgO 1.1 g kg^{-1} and C/N ratio 68.2 (Yeboah, 2009) [39].

pH, bulk density, cation exchange capacity, water retention, and biological activity are just a few of the soil parameters that are influenced by the application of biochar. According to Mandal *et al*. (2018) [24], these changes in soil characteristics are anticipated to have an effect on nutritional responses on soil particles and microbial metabolism of nutrients. By boosting the soil's nutrient content and nutrient mobility after application, biochar boosts crop productivity and soil fertility. It promotes aeration and water retention (Meier *et al*. 2019; Kambo and Dutta *et al*. 2015; Razzaghi *et al*. 2020) [27, 41, 32], buffers soil responses (Laghari *et al*. 2016) [19], lowers bulk density (Yan *et al*. 2019) [42], and preserves the structure of soil aggregates (Zhang *et al*. 2020) [40]. Additionally, by changing the soil pH, biochar decreases nutrient leaching and loss of nutrients through volatilization.

Materials and Methods

During Kharif 2021–2022, the field experiment was carried out on the Research Farm of the Department of Agronomy, Dr. PDKV, and Akola. Eight treatments and three replications were used in the experiment's Randomized Block Design (RBD).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 5.0 t ha^{-1}, $T_{7:}$100% RDN+ Biochar 5.0 t ha^{-1} & T_8: 125% RDN + Biochar 5.0 t ha^{-1}. The recommended dose of fertilizer was 120: 60:30 N, P_2O_5 and K_2O kg ha^{-1}. Biochar at the rate of 2.5 & 5.0 t ha^{-1} was applied one week before sowing according to the respective treatments. Nitrogen in the form of urea (46% N) was applied as per the treatments in two splits doses i.e., basal dose and at 30 DAS. Full dose of P_2O_5 and K_2O were applied in the form of SSP (16% P_2O_5) and MOP (60% K_2O) to all the treatments as per recommended dose of fertilizers (120-60-30 N, P, K kg ha^{-1}) except treatment control.

Biochar was analyzed for the different parameters as per the following methods. pH & EC (1:10 solution) were determined using pH meter & conductivity meter respectively (Jackson, 1973) [17], total organic carbon by Dry combustion method (Batjes, 2005) [6], total nitrogen by Micro-Kjeldahl's distillation method (Keeny & Nelson, 1982) [18], total phosphorus by Modified procedure of Change and Jackson (Peterson & Corey, 1966) [30], total potassium by H_2SO_4, $HClO_4$ and HF digestion (Jackson, 1973) [17] &C:N ratio by Dry Combustion: Micro Kjeldahl method (Batjes, 2005: Keeny & Nelson, 1982) [6, 18].

The soil samples were collected before sowing and after harvest of maize and analyzed for various physical and chemical properties of the soil by following standard procedures. Bulk density was determined by clod coating method (Blacke & Hartage 1986) [7], maximum water holding capacity by Keen Reck zonski boxes (Gupta & Dakshina moorthi, 1980) [13], Soil pH & EC (1:2.5 solution) were determined using pH meter & conductivity meter respectively (Jackson, 1973) [17], organic carbon content by wet oxidation method (Nelson & Sommers, 1982) [18], available nitrogen by alkaline potassium permanganate distillation method (Subbiah & Asija, 1956) [35], available phosphorus by 0.5 M $NaHCO_3$ using spectrophotometer (Watanabe and Olsen, 1965) [38], available potassium by flame photometrically (Jackson, 1973) [17], available micronutrients (Zn, Cu, Fe & Mn) by DTPA extract using AAS (Lindsay & Norvell, 1978) [23]. The quantity of SOC stock at each depth was calculated by using the formula

SOC stock (Mg ha^{-1}) = Soil OC (%) × Bulk density (Mg m^{-3}) × Depth (cm) (Batjes, 1996) [5].

The grain and straw yield were recorded & expressed in appropriate unit. The data were subjected to statistical analysisas per Gomez & Gomez (1984) [12].

Results and Discussion

Chemical composition of biochar

The chemical properties of biochar indicates that pH, EC and total carbon content were 8.70, 0.60 (dSm^{-1}) & 32.13% respectively (Table 1), while the total nitrogen, phosphorus and potassium content were 0.471%, 0.227% and 1.26% respectively and C:N ratio was 68.2%. The biochar prepared from different crop residues was alkaline in nature with pH 8.70. Similar properties were observed by Laharia *et al*. (2020) [20].

Table 1: Chemical composition of biochar

Sr. No.	Properties	Value
1.	pH (1:10)	8.70
2.	EC (dSm^{-1})	0.60
3.	Total Carbon (%)	32.13
4.	Total Nitrogen (%)	0.471
5.	Total Phosphorus (%)	0.227
6.	Total Potassium (%)	1.26
7.	C:N ratio	68.2

Yield of maize

Significantly highest grain (48.53 q ha^{-1}) & straw yield (77.35 q ha^{-1}) yield of maize (Table 2) were recorded with the application of 125% RDN + Biochar 5 t ha^{-1} (T_8). The highest grain and straw yield of maize was recorded in the treatment T_8while the lowest yield was observed under the treatment T_1.

Table 2: Yield of maize as influenced by various treatments

Treatments		Yield of maize (q ha^{-1})	
		Grain	Straw
T_1	Control	23.35	38.60
T_2	100% RDN	44.24	71.30
T_3	75% RDN +Biochar 2.5 tha^{-1}	39.85	64.25
T_4	100% RDN + Biochar 2.5 t ha^{-1}	45.63	72.40
T_5	125% RDN +Biochar 2.5 t ha^{-1}	47.22	75.65
T_6	75% RDN + Biochar 5 t ha^{-1}	41.80	66.70
T_7	100% RDN +Biochar 5 t ha^{-1}	46.44	74.10
T_8	125% RDN + Biochar 5 t ha^{-1}	48.53	77.35
	S.E. (m)±	1.07	1.67
	C.D. at 5%	3.18	4.98

The grain and straw yield of maize was 107.83% and 100.38% higher in treatment best as compare to control. This might be due to the increase in rate of biochar which increases the nutrient supply and moisture content in soil. The performance of integrated treatments similar to sole inorganic might be due to a better and continuous availability of nutrients to the plants up to cob development which increased the grain yield (Gokila and Baskar, 2015) [15] and timely availability of nitrogen from organic sources increased the photosynthetic surface, greater chlorophyll content contributed to larger dry matter accumulation and better crop growth (Arif *et al.*, 2012) [3]. Similar results were recorded by Ali *et al.* (2020) [1].

Physical properties of soil
Bulk density (BD)
The result of findings observed that the bulk density of soil at harvest of crop wasfound significant by various treatments over control and there was a numerical reduction in bulk density in all the biochar applied treatments than without biochar treatments i.e. T_1 and T_2 (Table 3) might be due to biochar addition in the soil, as biochar itself has low density material and diluted the mineral fraction in the soil. Similar result given by Horak *et al.* (2019) [14] who reported that biochar addition in the soil had a positive effect on the reduction of soil bulk density, which is related to the specific density of the increasing application rate of biochar.

Table 3: Physical properties of soil after harvest of maize

Treatments		Bulk Density (Mg m^{-3})	Water holding Capacity (%)
T_1	Control	1.58	47.74
T_2	100% RDN	1.57	48.21
T_3	75% RDN + Biochar2.5 t ha^{-1}	1.54	50.12
T_4	100% RDN +Biochar 2.5 t ha^{-1}	1.53	51.30
T_5	125% RDN + Biochar 2.5 t ha^{-1}	1.53	51.71
T_6	75% RDN + Biochar 5 t ha^{-1}	1.52	55.80
T_7	100% RDN +Biochar 5 t ha^{-1}	1.51	56.18
T_8	125% RDN +Biochar 5 t ha^{-1}	1.51	57.35
	S.E. (m)±	0.01	2.43
	C.D. at 5%	0.03	7.27

Water holding capacity (WHC)
The result (Table 3) indicated that there was significant increase in water holding capacity of soil by various treatments. Higher water holding capacity (57.35%) was recorded with application of 125% RDN + Biochar 5 t ha^{-1} (T_8) and it was at par with the treatments T_7,T_6, T_5, T_4,T_3whereas, the lower water holding capacity (47.74%) was recorded in control. The increase in water holding capacity of soil due to biochar because it has high specific surface area, extensive pore structure which increases soil micro porosity in sandy soils and also due to high absorptive nature of biochar to water. Similar finding quoted by Sun *et al.* (2013) [37] who reported that the increase in WHC of soil after biochar addition due to changes in soil structure, increase in porosity and capillary function.

Chemical properties of soil
Soil pH

Table 4: Chemical properties of soil after harvest of maize

Treatments		pH	EC (dSm^{-1})	OC (g kg^{-1})
T_1	Control	7.71	0.27	5.90
T_2	100% RDN	7.69	0.27	6.07
T_3	75% RDN +Biochar2.5 t ha^{-1}	7.68	0.28	6.23
T_4	100% RDN +Biochar 2.5 t ha^{-1}	7.67	0.29	6.27
T_5	125% RDN +Biochar 2.5 t ha^{-1}	7.67	0.29	6.30
T_6	75% RDN + Biochar 5 t ha^{-1}	7.66	0.30	6.43
T_7	100% RDN +Biochar 5 t ha^{-1}	7.65	0.31	6.46
T_8	125% RDN +Biochar 5 t ha^{-1}	7.65	0.31	6.48
	S.E. (m)±	0.01	0.006	0.02
	C.D.at 5%	-	-	0.06

The pH of soil ranges from 7.71 to 7.65 indicating the soil was moderately alkaline in reaction. Higher pH (7.71) was recorded in control (T_1) while the lower pH (7.65) was recorded in treatment T_8 & T_7 (Table 4). The result of the study indicated that the soil pH was slightly decline and found non-significant by various treatments and it may be due to buffering capacity of biochar and protonation of organic anions on the surface of the biochar. The formation of the acidic functional groups can neutralize soil alkalinity eventually decreasing the soil pH.Similar results were recorded by Lee *et al.* (2021) [21].

Electrical conductivity
The electrical conductivity (EC) was ranged from 0.27 to 0.31 dSm^{-1}, the highest EC (0.31) was recorded in treatment T_8& T_7 while the lowest EC (0.27) was recorded in control (Table 4). The result of the study showed that the EC was increased with the application of biochar but found non-significant by various treatments and it may be due to the soluble salt concentration and exchangeable cations in wood biochar which can increase the EC in treated plot as compared to untreated plot. The non-significant influence could be due to non-saline nature of biochar as reported by Nigussie *et al.* (2012) [29]. Similar results were noted by Laharia *et al.* (2020) [20].

Organic carbon
The organic carbon content in the soil was varied from 5.90 to 6.48 g kg^{-1} indicating that the soil was medium to moderately high in organic carbon. Significantly higher organic carbon content in the soil (6.48 g kg^{-1}) was recorded with the application of 125% RDN + Biochar 5 t ha^{-1} (T_8) which was found at par with treatments T_7 & T_8 (Table 4) and it might be due to high amount of organic carbon in the added biochar, the huge surface area of biochar and mineralization of organic matter absorbed by biochar particles which in turn provides micropores for beneficial micro-organisms habitat thereby increasing the organic carbon content in soil at harvest. Significant increase in the organic carbon content by biochar addition was also reported by Masulili *et al.* (2010) [26] and Islami *et al.* (2011) [16].

Available NPK status of soil
The available NPK status in the soil after harvest of maize

was found significant with the application various treatments. Significantly higher available nitrogen (254.42 kg ha^{-1}), phosphorus (22.65 kg ha^{-1}) and potassium (387 kg ha^{-1}) were recorded with the application of 125% RDN + Biochar 5 t ha^{-1} (T_8) and it was found statistically on par with treatments T_7, T_5, T_4 & T_2 (Table 5). Available nitrogen in soil was increased due to the biochar, which can play an essential role in the nutrient cycle and thus affecting N retention in soil was recorded by Gao *et al.* (2018) [10], available phosphorus was increase in soil treated with biochar might be due to increased microbial population, which solubilize insoluble fixed phosphorus thereby, increase its availability noticed by IslamI *et al.* (2011) [16] and Petter *et al.* (2012) [31] and available potassium was also increased in soil with application biochar might be due to the high concentration of potassium found in the biochar (Chan *et al.*, 2007) [8].

Table 5: Available nutrient status of soil as influenced by various treatments

Treatments		Available nutrient (kg ha^{-1})		
		Nitrogen	Phosphorus	Potassium
T_1	Control	217.76	15.42	324
T_2	100% RDN	241.12	18.66	364
T_3	75% RDN +Biochar2.5 tha^{-1}	231.72	16.82	347
T_4	100% RDN +Biochar 2.5 t ha^{-1}	245.43	19.24	372
T_5	125% RDN +Biochar 2.5 t ha^{-1}	251.72	20.45	381
T_6	75% RDN + Biochar 5 t ha^{-1}	235.22	17.69	358
T_7	100% RDN +Biochar 5 t ha^{-1}	248.56	21.65	381
T_8	125% RDN +Biochar 5 t ha^{-1}	254.42	22.65	387
	S.E. (m)±	4.45	1.52	8.35
	C.D. at 5%	13.36	4.02	25.03

DTPA extractable micronutrients in soil

The higher available Zn (0.64 mg kg^{-1}), Cu (2.39 mg kg^{-1}), Fe (4.45 mg kg^{-1}) & Mn (9.49 mg kg^{-1}) were recorded with the application of 125% RDN + Biochar 5 t ha^{-1} (T_8) over remaining treatments (Table 6) while lower values were recorded in control. The results indicated that increase in the doses of biochar showed slight increase in available Zn, Cu, Fe & Mn but, were found non-significant by various treatments. Salmani *et al.* (2014) [33] reported the result that Cu content in the biochar amended soil was significantly higher as compared to soils with no biochar amendment when no copper was applied externally. Increase in the available manganese content on biochar addition as biochar acts as a source of manganese (Lentz & Ippoliti, 2011) [22]. Hass *et al.* (2012) [43] reported the similar result that application of biochar increased the extractable micronutrients (Zn, Cu, Fe & Mn) in the soil.

Table 6: Available micronutrients in soil as influenced by various treatments

Treatments		Available micronutrients (mg kg^{-1})			
		Zn	Cu	Fe	Mn
T_1	Control	0.55	2.17	4.25	9.21
T_2	100% RDN	0.56	2.20	4.28	9.27
T_3	75% RDN +Biochar2.5 tha^{-1}	0.58	2.24	4.30	9.30
T_4	100% RDN +Biochar 2.5 t ha^{-1}	0.58	2.26	4.32	9.35
T_5	125% RDN +Biochar 2.5 t ha^{-1}	0.59	2.27	4.33	9.38
T_6	75% RDN + Biochar 5 t ha^{-1}	0.61	2.33	4.37	9.43
T_7	100% RDN +Biochar 5 t ha^{-1}	0.63	2.36	4.43	9.47
T_8	125% RDN +Biochar 5 t ha^{-1}	0.64	2.39	4.45	9.49
	S.E. (m)±	0.03	0.07	0.06	0.09
	C.D. at 5%	-	-	-	-
		0.53	2.16	4.23	9.20

Table 7: Soil organic carbon (SOC) stock as influenced by various treatments

Treatments		SOC Stock (Mg ha^{-1})
T_1	Control	18.64
T_2	100% RDN	19.06
T_3	75% RDN +Biochar2.5 t ha^{-1}	19.13
T_4	100% RDN +Biochar 2.5 t ha^{-1}	19.19
T_5	125% RDN +Biochar 2.5 t ha^{-1}	19.28
T_6	75% RDN + Biochar 5 t ha^{-1}	19.54
T_7	100% RDN +Biochar 5 t ha^{-1}	19.56
T_8	125% RDN +Biochar 5 t ha^{-1}	19.60
	S.E. (m)±	0.02
	C.D. at 5%	0.08

Soil organic carbon (SOC) stock

Significantly the higher soil organic carbon (SOC) stock (19.60 Mg ha^{-1}) was recorded with the application of 125% RDN + Biochar 5 t ha^{-1} (T_8) which was found statistically at par with treatments T_7& T_6 (Table 7). Higher the quantity of biochar applied, higher soil organic carbon (SOC) stock was recorded, this is because biochar amendment enhances microbial activity and accelerated the decomposition of soil organic carbon (Dahal *et al.* (2018) [9] also noticed that biochar application can enhance accumulation of carbon in the form of above ground biomass and soil organic carbon which increases the incremental rates of SOC stocks in all the biochar treated plots as compared to control.

Nutrient use efficiency

The highest nitrogen use efficiency (41.97 kg) was noted with the application of 75% RDN + Biochar 5 t ha^{-1} (T_6) while lowest nitrogen use efficiency (27.50 kg) was recorded with application of 125% RDN + Biochar 2.5 t ha^{-1} (T_5). From the above result, it was noticed that nitrogen use efficiency was increased as the dose of biochar increases from 2.5 to 5.0 t ha^{-1}.

Table 8: Effect of biochar on nutrient use efficiency

Treatments		Nutrient use efficiency (kg yield per kg nutrient)		
		Nitrogen	Phosphorus	Potassium
T_1	Control	---	---	---
T_2	100% RDN	34.82	17.41	69.65
T_3	75% RDN +Biochar2.5 tha^{-1}	27.50	18.33	55.00
T_4	100% RDN +Biochar 2.5 t ha^{-1}	37.13	18.56	74.26
T_5	125% RDN +Biochar 2.5 t ha^{-1}	39.78	15.91	79.56
T_6	75% RDN + Biochar 5 t ha^{-1}	30.75	20.50	61.50
T_7	100% RDN +Biochar 5 t ha^{-1}	38.48	19.24	76.96
T_8	125% RDN +Biochar 5 t ha^{-1}	41.97	16.77	83.93

Highest use efficiency of phosphorus (20.50 kg) and potassium (83.93 kg) was recorded with the application of 125% RDN + Biochar 5 t ha^{-1} (T_8) followed by application of 125% RDN + Biochar 2.5 t ha^{-1} (T_5) and it might be due to greater yield of maize recorded on biochar amended soils contributed to improve nutrient uptake and nutrient use efficiency. Lowest use efficiency of phosphorus (15.91 kg) and potassium (55.00 kg) was recorded with application of 75% RDN + Biochar 2.5 t ha^{-1} (T_3). Similarly, Badu *et al.* (2019) [4] reported that the interaction between biochar and inorganic nitrogen rate significantly influenced nitrogen use efficiency by maize.

Conclusion

From the present investigation, it can be concluded that, the soil application of 100% RDN+ Biochar5 t ha^{-1} favorably influenced the yield of maize as well as improved the soil properties.

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