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Effect of biochar on yield, quality and uptake of nutrients by maize grown on a vertisol in Maharashtra, India

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ABSTRACT

The field experiment was conducted during *Kharif,* 2020-21, to study the effect of biochar on yield, quality and uptake of nutrients by maize grown in a vertisol on the Research Farm of the Department of Agronomy, Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola. The experiment was laid out in Randomized Block Design with eight treatments and three replications. The treatments comprised of control, various levels of nitrogen and their combinations with 2.5 and 5.0 t ha^{-1} biochar. On the basis of the results obtained, significantly higher grain (45.33 q ha^{-1}) and straw yield (74.57 q ha^{-1}) of maize were recorded with the application of 125% recommended dose of nitrogen (RDN) + Biochar 5.0 t ha^{-1}. Significantly higher content, total uptakes of N (160.72 kg ha^{-1}), P (27.02 kg ha^{-1}) & K (132.44 kg ha^{-1}) by maize were recorded with the application of 125% RDN + biochar 5 t ha^{-1}. The test weight (27.43 g) and protein content (12.19%) were also significantly higher with the application of 125% RDN + biochar 5 t ha^{-1}. At the same time, the total carbohydrate and crude fiber content of maize grain was found non-significant by various treatments. The higher the dose of biochar applied, the higher the nutrient (N, P and K) use efficiency was recorded. From the present investigation, it can be concluded that the soil application of 100% RDN + Biochar 5 t ha^{-1} favourably influenced the yield, quality and uptake of nutrients by maize.

Keywords: Biochar, Yield of maize, Quality, Uptake of nutrients, nitrogen

INTRODUCTION

Agricultural wastes are important in soil agro-ecosystems as they add organic matter and ultimately provide essential plant nutrients, i.e. N, P and K. When these wastes are used to produce biochar, they bring about an opportunity to be used as a sustainable soil amendment. It may help to avoid further reduction of soil organic carbon (Gaskin *et al.,* 2008). Conversion of biowaste into biochar is a potential tool for reducing the ill effects of global climate change. In present years, biochar has emerged as an important amendment and has been found to have a positive impact on soil fertility, holding a promise to improve crop yield when combined with mineral fertilizer. Biochar is a fine-grained, carbon-rich, porous product, largely resistant to decomposition remaining after plant biomass that has been subjected to a thermo-chemical conversion process (pyrolysis) at low temperature (350-600°C) in an environment with little or no oxygen (Amonette and Joseph, 2009). During the pyrolysis process, biomass is heated to 250-700°C, producing volatile compounds condensed to give bio-oil. The other products produced from pyrolysis include a gaseous material called 'syngas' and a carbon-rich charcoal material called biochar (Lehmann, 2007).

Some of the common agricultural by-products available in large quantities include bagasse, rice husk, wheat straw, groundnut shell, tea waste, casuarina leaf litter, silk cotton shell, cotton waste, oil palm fiber and shells, cashew nut shell, coconut shell, coir pith etc. (Sugumaran and Sheshadri, 2009). Different studies have shown that both the pyrolysis temperature and the biomass used have an effect on the production characteristics of biochar for agricultural use (Sohi, 2012). Biochar is not a pure carbon but rather a mixture of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulphur (S) and ash in different proportions (Masek, 2009). Biochar contains more than 60% carbon and is rich in various nutrients and trace elements essential for plant growth, so it is also known as the "Black Gold" of agriculture. Chemically biochar contains 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).

Maize (*Zea mays L.*) belongs to the grass family Poaceae and is one of the most important cereal crops in India as well as in the world. It is also known as corn, makka or makki. The primary centre of origin of maize is considered to be Central America and Mexico. Globally, maize is known as the "Queen of cereals" because it has the highest genetic yield potential among cereals. It is the world's third most important annual cereal after rice and wheat in terms of area and production. Among the maize-growing countries, India ranks 4th in area and 7th in production, representing around 4% of the world maize area and 2% of total maize production. Among Indian states, Madhya Pradesh and Karnataka have the highest area under maize (15% each), followed by Maharashtra (10%).

Maize is widely processed into various types of products. It is known for its wider adaptability and multipurpose uses that provide food for human beings, feeds for animals, raw materials for industries, and bio-ethanol 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.

MATERIALS AND METHODS

The field experiment was conducted on the Research Farm, Department of Agronomy, Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola, during *Kharif,* 2020-21. The experiment was laid out in Randomized Block Design (RBD) with eight treatments and three replications. 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 2 split doses, i.e., basal dose and at 30 days after sowing (DAS). Full doses of P_2O_5 and K_2O were applied in the form of single super phosphate (SSP) (16% P_2O_5) and muriate of potash (MOP) (60 % K_2O) to all the treatments as per the 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 & electrical conductivity (EC) (1:2.5 solution) were determined using a pH meter and conductivity meter, respectively (Jackson, 1973), total carbon by dry combustion method (Batjes, 2005), total nitrogen by Micro-Kjeldahl's distillation method (Keeny & Nelson, 1982), total phosphorus by modified procedure of Chng and Jackson (Peterson & Corey, 1966), total potassium by H_2SO_4, $HCIO_4$ and HF digestion (Jackson, 1973), and C:N ratio by dry combustion: Micro Kjeldahl method (Batjes, 2005; Keeny & Nelson, 1982). After harvesting maize, plant samples were sun-dried for 2-3 days and used to analyze nutrient content in grains and straw and quality parameters of grain by following standard procedures. Total nitrogen was determined by micro-Kjeldahl's distillation method (Piper, 1966). Plant samples were digested with a di-acid mixture of HNO_3: $HCLO_4$ (9:4) & the clear extract was used for the determination of P and K. Total phosphorous was estimated by spectro-photometer (Jackson, 1973), and total potassium by a flame photometer (Piper, 1966) method. A hundred kernels were taken randomly from the net plot of each treatment, and their weight was recorded as test weight in grams. The protein percentage was determined by multiplying the percentage of nitrogen content in grain by a constant factor of 6.25 (AOAC, 1990). Crude fiber content was estimated by using the loss in the ignition method (Maynard, 1970), and total carbohydrate was estimated by Anthrone method (Hodge J.E. and B.T. Hofreiterm, 1962). The uptake of nutrients (N, P and K) was worked out by considering grain and dry matter yield at harvest in particular plots in relation to the concentration of particular nutrients in respective plots by using the following formula and the data were subjected to statistical analysis as described by Gomez and Gomez (1984).

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient content (\%) in grain/straw} \times \text{yield of grain/straw (kg ha}^{-1}\text{)}}{100}$$

Agronomic Efficiency (AE) is a part of NUE and calculated in units of yield increases per unit nutrient applied by using the following formula (Bhatnagar, 2017)

$$\text{Agronomic efficiency (kg kg}^{-1}\text{)} = \frac{\text{Grain yield in fertilized plot (kg ha}^{-1}\text{)} - \text{Grain yield in unfertilized plot (kg ha}^{-1}\text{)}}{\text{Amount of nutrient applied (kg)}}$$

RESULTS AND DISCUSSION

Chemical composition of biochar

The chemical properties of biochar indicate that pH, EC and total organic carbon content were 8.70, 0.60 (dSm^{-1}) & 74.14%, respectively (Table 1). The total nitrogen, phosphorus and potassium content were 0.471%, 0.227% and 1.26%, respectively and C:N ratio was 157.40%. The biochar prepared from different crop residues was alkaline in nature with pH 8.7. Similar properties were observed by Pandian *et al.* (2016) and Laharia *et al.* (2020).

Table 1. Chemical composition of biochar

Properties	Value
pH (1:2.5)	8.70
EC (dSm^{-1})	0.60
Total carbon (%)	74.14
Total nitrogen (%)	0.471
Total phosphorus (%)	0.227
Total potassium (%)	1.26
C:N ratio	157.40

Yield of maize

Significantly higher grain (45.33 q ha^{-1}) and straw yield (74.57 q ha^{-1}) yield of maize (Table 2) were recorded with the application of 125 % RDN + Biochar 5 t ha^{-1} (T_8), which was found to be at par with treatments T_5, T_7, T_4, and T_2 . This might be due to the increase in the rate of biochar, which increases the nutrient supply and moisture content in the soil. The performance of integrated treatments similar to sole inorganic might be due to better and continuous availability of nutrients to the plants up to cob development increased the grain yield (Gokila and Baskar, 2015) 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). Similar results were reported by Ali *et al.* (2020)

Table 2. Yield of maize as influenced by various treatments

Treatments		Yield of maize (q ha^{-1})	
		Grain	Straw
T_1	Control	24.86	42.78
T_2	100 % RDN	41.74	69.22
T_3	75 % RDN + Biochar 2.5 tha^{-1}	37.75	61.13
T_4	100 % RDN + Biochar 2.5 t ha^{-1}	42.23	70.12
T_5	125 % RDN + Biochar 2.5 t ha^{-1}	44.72	73.39
T_6	75 % RDN + Biochar 5 t ha^{-1}	39.84	64.78
T_7	100 % RDN + Biochar 5 t ha^{-1}	43.53	72.55
T_8	125 % RDN + Biochar 5 t ha^{-1}	45.33	74.57
	SE (m)±	1.49	3.22
	CD at 5%	4.48	9.67

Quality parameters of maize

Test weight

The test weight of maize grain was found to vary from 25.13 to 27.43 g. A significantly higher test weight (27.43 g) was recorded with the application of 125% RDN+ Biochar 5.0 t ha^{-1} (T8), and it was found to be on par with treatments T5, T7, T4 and T2. It might be due to increasing the rate of biochar, which provides the necessary minerals and improved content in grains, resulting in greater grain size and grain weight. A similar result was noted by Imran et al. (2014), who reported that an increase in biochar levels significantly increased the test weight of maize over the control. Arif et al. (2012) also reported that the test weight of sweet corn increases with the application of biochar over the control.

Protein content

The result revealed that the protein content of maize grain varied from 11.06 to 12.19% and significantly increased with various treatments over the control. The higher protein content (12.19%) was recorded with the application of 125% RDN+ Biochar 5.0 t ha^{-1} (T_8), and it was found to be on par with the treatments T_7, T_5, T_4, T_6 & T_2 (Table 3). The

Table 3. Quality parameters of maize as influenced by various treatments

Treatments	Test weight (gm)	Protein (%)	Total carbohydrate (%)	Crude fiber (%)
T_1 Control	25.13	11.06	64.04	0.75
T_2 100 % RDN	27.07	11.69	65.14	0.84
T_3 75 % RDN + Biochar 2.5 tha^{-1}	26.44	11.25	64.74	0.81
T_4 100 % RDN + Biochar 2.5 t ha^{-1}	27.33	11.75	65.20	0.87
T_5 125 % RDN + Biochar 2.5 t ha^{-1}	27.39	11.94	66.01	0.94
T_6 75 % RDN + Biochar 5 t ha^{-1}	26.64	11.69	65.72	0.83
T_7 100 % RDN + Biochar 5 t ha^{-1}	27.37	12.06	66.52	0.93
T_8 125 % RDN + Biochar 5 t ha^{-1}	27.43	12.19	66.88	0.96
SE (m)±	0.12	0.17	0.80	0.05
CD at 5%	0.38	0.52	-	-

lowest Protein content (11.06%) was recorded in the control. The significant increase in protein content with the biochar application was due to a higher supply of nitrogen throughout the crop growth period and increased nitrogen content in grain, which is an integral part of the protein. The present result is in accordance with the findings of Vasanthi and Subramanian (2004). A similar result was noted by Idikut *et al*. (2009), who reported that protein content in maize grain was increased due to the increased availability of nitrogen and its uptake and storage in grain.

Carbohydrate content

The carbohydrate content of maize grain was slightly increased but non-significant among various treatments. The highest carbohydrate content (66.88%) was recorded with the application of 125% RDN+ Biochar 5.0 t ha^{-1} (T_8) over the remaining treatments (Table 3). These results are confirmed by Ogunyemi *et al.* (2018), who reported that maize treated with sawdust biochar had the highest carbohydrate content (80.31%) than NPK-applied-soil and control treatments.

Crude fiber content

The higher crude fiber content (0.96%) was recorded with the application of 125% RDN+ Biochar 5.0 t ha^{-1} (T_8) over other treatments but found non-significant by various treatments. A similar finding was quoted by Cortez & Altamirano (1972), who reported that crude fiber content in the maize grain might vary depending on the type and genotype of maize.

Uptake of nutrients by maize

Uptake of nitrogen

Significantly higher uptake of nitrogen by grain (88.39 kg ha^{-1}) was recorded with the application of 125% RDN + Biochar 5 t ha^{-1} (T_8), and it was found to be on par with treatments T_5, T_7, T_4 and T_2. Significantly higher uptake of nitrogen by straw (72.33 kg ha^{-1}) was recorded with the application of 125% RDN + Biochar 5 t ha^{-1} (T_8), and it was found to be on par with treatments T_7, T_5, T_4, T_2 and T_6 (Table 4). Significantly, the total uptake of nitrogen by maize was higher (160.72 kg ha^{-1}) with the application of 125% RDN + Biochar 5 t ha^{-1} (T_8),

Table 4. Content and uptake of nitrogen by maize

Treatments	Nitrogen Content (%)		Nitrogen uptake(kg ha^{-1})		
	Grain	Straw	Grain	Straw	Total
T_1 Control	1.77	0.77	44.00	32.94	76.94
T_2 100 % RDN	1.87	0.86	78.05	59.53	137.58
T_3 75 % RDN + Biochar 2.5 tha^{-1}	1.80	0.85	67.95	51.96	119.91
T_4 100 % RDN + Biochar 2.5 t ha^{-1}	1.88	0.88	79.39	61.71	141.10
T_5 125 % RDN + Biochar 2.5 t ha^{-1}	1.91	0.94	85.42	68.99	154.41
T_6 75 % RDN + Biochar 5 t ha^{-1}	1.87	0.90	74.50	58.30	132.80
T_7 100 % RDN + Biochar 5 t ha^{-1}	1.93	0.96	84.01	69.65	153.66
T_8 125 % RDN + Biochar 5 t ha^{-1}	1.95	0.97	88.39	72.33	160.72
SE (m)±	0.037	0.03	3.49	4.74	8.12
CD at 5%	0.11	0.11	10.48	14.23	24.37

Table 5. Content and uptake of phosphorus by maize

Treatments	Phosphorus content (%)		Phosphorus uptake (kg ha^{-1})		
	Grain	Straw	Grain	Straw	Total
T_1 Control	0.24	0.11	5.97	4.71	10.68
T_2 100 % RDN	0.27	0.16	11.27	11.08	22.35
T_3 75 % RDN + Biochar 2.5 tha^{-1}	0.26	0.14	9.82	8.56	18.38
T_4 100 % RDN + Biochar 2.5 t ha^{-1}	0.28	0.16	11.82	11.22	23.04
T_5 125 % RDN + Biochar 2.5 t ha^{-1}	0.29	0.16	12.97	11.74	24.71
T_6 75 % RDN + Biochar 5 t ha^{-1}	0.27	0.15	10.76	9.72	20.48
T_7 100 % RDN + Biochar 5 t ha^{-1}	0.29	0.17	12.62	12.33	24.95
T_8 125 % RDN + Biochar 5 t ha^{-1}	0.30	0.18	13.60	13.42	27.02
S.E.(m)±	0.010	0.006	0.78	0.80	1.56
CD at 5%	0.031	0.019	2.35	2.41	4.70

which was found to be on par with $T_{5,}$ $T_{7,}$ $T_{4,}$ and T_2. An increased application rate of biochar increased biomass production, which increased nutrient uptake.

The increasing content and uptake of nitrogen by maize crop in biochar-treated plots might be due to a decrease in nitrogen loss and a slow-release pattern of nitrogen synchrony with the demand by maize crop, increasing the nitrogen content of tissues. The higher uptake of nitrogen under high doses of biochar may be due to the positive effects of biochar on crop growth, along with positive effects on nutrient (P, K, Ca and Mg) uptake by crop plants. Similar findings were also noticed by Chan *et al.* (2007), who reported that higher biochar amendment increased nitrogen uptake by radish plants.

Uptake of phosphorus

Significantly higher uptake of phosphorus by maize grain (13.60 kg ha^{-1}) and straw (13.42 kg ha^{-1}) was recorded with the application of 125% RDN + Biochar 5 t ha^{-1} (T_8), and it was on par with the treatments $T_{7,}$ $T_{5,}$ T_4 and T_2 (Table 5). Significantly higher total uptake of phosphorus (27.02 kg ha^{-1}) by maize was recorded with the application of 125% RDN + Biochar 5 t ha^{-1} (T_8), and it was on par with the treatment T_7, $T_{5,}$ T_4&. Higher concentration and uptake of phosphorus may be due to more phosphorus availability to crops through the addition of biochar and also due to improved physical and chemical properties of soil. Chng *et al.* (2016) reported a similar result that the application of poultry manure biochar and pineapple leaves compost increased phosphorus concentration and uptake in maize.

Uptake of potassium

Significantly higher uptake of potassium by maize grain (23.57 kg ha^{-1}) and straw (108.87 kg ha^{-1}) was recorded with the application of 125% RDN + Biochar 5 t ha^{-1} (T_8), and it was on par with treatments T_7, T_5 T_4 and T_2 (Table 6). Significantly higher total uptake potassium (132.44 kg ha^{-1}) by maize was recorded with the application of 125% RDN+ Biochar 5 t ha^{-1} (T_8), and it was on par with treatment $T_{7,}$ $T_{5,}$ T_4 & T_2. The increase in

Table 6. Content and uptake of potassium by maize

Treatments	Potassium content (%)		Potassium uptake(kg ha^{-1})		
	Grain	Straw	Grain	Straw	Total
T_1 Control	0.42	1.23	10.44	52.62	63.06
T_2 100 % RDN	0.47	1.42	19.62	98.29	117.91
T_3 75 % RDN + Biochar 2.5 tha^{-1}	0.45	1.40	16.99	85.58	102.57
T_4 100 % RDN + Biochar 2.5 t ha^{-1}	0.48	1.43	20.27	100.27	120.54
T_5 125 % RDN + Biochar 2.5 t ha^{-1}	0.49	1.45	21.91	106.42	128.33
T_6 75 % RDN + Biochar 5 t ha^{-1}	0.46	1.42	18.33	91.99	110.32
T_7 100 % RDN + Biochar 5 t ha^{-1}	0.51	1.45	22.20	105.20	127.70
T_8 125 % RDN + Biochar 5 t ha^{-1}	0.52	1.46	23.57	108.87	132.44
SE (m)±	0.016	0.014	1.32	3.53	5.27
CD at 5%	0.049	0.043	3.97	10.61	15.83

Table 7. 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	14.07	28.13	56.27
T_3 75 % RDN + Biochar 2.5 tha^{-1}	14.32	21.48	42.97
T_4 100 % RDN + Biochar 2.5 t ha^{-1}	14.48	28.95	57.90
T_5 125 % RDN + Biochar 2.5 t ha^{-1}	13.24	33.10	66.20
T_6 75 % RDN + Biochar 5 t ha^{-1}	16.64	24.97	49.93
T_7 100 % RDN + Biochar 5 t ha^{-1}	15.56	31.11	62.23
T_8 125 % RDN + Biochar 5 t ha^{-1}	13.65	34.12	68.23

concentration and uptake of potassium may be due to the ash content of biochar, which helps immediately release occluded mineral nutrients like potassium for crop use. Moreover, biochar can increase the CEC of soil, thereby increasing the ability of soil to hold potassium and make it available for plant uptake. Higher CEC of biochar reduced the losses of potassium and thus increased the potassium uptake; the result was in conformation with Lehmann *et al.* (2011). Abrishamkesh *et al.* (2015) also noticed that high ash content in biochar-amended soils could be attributed to an immediate release of potassium from the ash, which could result in higher uptake of potassium by the plant.

Nutrient use efficiency

The highest nitrogen use efficiency (16.64 kg kg^{-1}) was recorded with the application of 75% RDN + Biochar 5 t ha^{-1} (T_6), while lower nitrogen use efficiency (13.24 kg) was recorded with the application of 125% RDN + Biochar 2.5 t ha^{-1} (T_5) (Table 7). From the above result, it was noticed that nitrogen use efficiency was increased as the dose of biochar increased from 2.5 to 5.0 t ha^{-1}. The highest use efficiency of phosphorus (34.12 kg) and potassium (68.23 kg) was recorded with the application of 125% RDN + Biochar 5 t ha^{-1} (T_8) followed by the 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 improving nutrient uptake and nutrient use efficiency. The lowest use efficiency of phosphorus (21.48 kg) and potassium (42.97kg) was recorded with the application of 75 % RDN + Biochar 2.5 t ha^{-1} (T_3). Similarly, Badu *et al.* (2019) 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 + Biochar 5 t ha^{-1} favourably influenced maize's yield, quality and uptake of nutrients. The higher the dose of biochar applied, the higher the nutrient (N, P and K) use efficiency was recorded. Further investigations must be undertaken to ascertain if even more elevated amounts of biochar would lead to similar trends.

CONFLICT OF INTEREST: The authors have no conflict of interest

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