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Impact of Different Sources and Levels of Biochar on Maize Growth and Yield in a Vertisol

Nagaveni H. C. [a++*], N. S. Hebsur [a#], V. B. Kuligod [a#], S. Rajkumar [b#] and P. Jones Nirmalanath [c#]

[a] *Department of Soil Science and Agricultural Chemistry, UAS, Dhrawad, India.*
[b] *Department of Agronomy, UAS, Dhrawad, India.*
[c] *Department of Agricultural Microbiology, UAS, Dhrawad, India.*

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

Biochar preparation is one of the beneficial technologies for crop residue management. The production and use of biochar have many opportunities for soil improvement and agricultural productivity. A field experiment was laid out in Factorial RBD, to assess the potential effect of biochar derived from maize cob rind, coconut shell and *Prosopis sps* on growth and yield of maize grown in *Kharif* season 2022. Treatments comprised of first factor as biochar sources *viz.,* maize cob rind biochar, *Prosopis sps* biochar and coconut shell biochar, second factor as application rates *viz.,* 7.5, 10 and 15 t ha^{-1} along with RPP without FYM, RPP and absolute control with three replications. Among the different biochar sources PSB recorded significantly higher total dry matter (188.21 g $plant^{-1}$), grain weight per cob (174.44 g cob^{-1}), grain yield (59.60 q ha^{-1}) and Stover yield

[++] *Ph. D scholar;*
[#] *Professor;*
**Corresponding author: E-mail: nagu.hcsn@gmail.com;*

(81.22 q ha^{-1}). Among the different rates of biochar application, significantly higher total dry matter (196.00 g plant^{-1}), grain weight per cob (183.02 g cob^{-1}), grain yield (57.55 q ha^{-1}), stover yield (88.94) were recorded with biochars application of 15 t ha^{-1}. However, lower values were recorded in absolute control. Among the Interaction effect between the sources and rate of biochar application was found to be non- significant with yield and soil parameters. Therefore, effect of biochar on the availability of soil nutrients is associated with the nature of the biochar feedstock, the rate of application and the soil characteristics.

Keywords: Biochar; yield; levels; kharif maize; sources.

1. INTRODUCTION

Maize is one of the most important cereal crops of India and plays a dominant role in the industrial and agricultural economy of India. In order to attain higher yields, indiscriminate use of inorganic fertilizers and pesticides has led to decline in soil fertility and undesirable side effects leading to soil beneficial microorganisms and contamination of food, water and environmental pollution leading to endangerment of human health [1]. This phenomenon has urged to improve the soil health and quality in sustainable manner along with attaining higher yield.

The use of biochar, a carbonaceous material produced via pyrolysis of locally available biomass has been shown profound effectiveness in improving the physical, chemical and biological properties with effective retaining capability of most nutrients to the crop [2]. Most of the crop and agroforestry residues from rainfed areas are burnt in the field due to difficulties in disposing the heavy residues creating a necessity for biochar production [3]. Biochar can be produced from agricultural residues and by products which cannot fetch monetary return like cobs of maize and pearlmillet, stalks from cotton and maize, straws from rice and wheat, along with agro-industrial waste like paper mill waste, jatropha husk, coffee husk, coconut shell and cocoa pod husk can be effectively utilized for the preparation of biochar [4].

Biochar application results in decrease in soil bulk density, increasing soil fertility and structure, improved water holding capacity, organic carbon content, availability of nutrients and biological properties [5]. Moreover, it also serves as a better alternate for other organic manures as it does similar work as that of FYM and other composts, but, in a compact and effective way yielding earlier crop response. The present study has been formulated in order to evaluate the impact of different sources of biochar supplied in different doses on the growth, yield parameters of maize.

2. MATERIALS AND METHODS

Field experiment was carried out during 2021-22 *Kharif* to study the potential effect of biochar derived from maize cob rind, *Prosopis sps* and coconut shell biochar on growth and yield of maize grown under rainfed condition. The soil of the experimental site was clayey in texture which was neutral in nature (pH 7.33), with low salt content (0.20 dSm^{-1}) and low organic carbon content (4.50 g ka^{-1}). The available nitrogen (113.00 kg ha^{-1}) was low, available phosphorus (38.50 kg ha^{-1}) was medium, available potassium (538.00 kg ha^{-1}) status was high. The exchangeable Ca and Mg were 21.00 and 12.0 c mol (p+) kg^{-1}, available sulphur 16.0 mg kg^{-1}, and all the DTPA extractable micronutrients were above the critical limit (Fe - 4.69, Mn -5.25, and Cu - 2.10 mg kg^{-1}) except Zn (0.55 mg kg^{-1}). The experiment was including twelve treatments consisting of 3 sources of biochar viz., maize cob rind biochar, *Prosopis sps* biochar and coconut shell biochar and 3 levels of biochar at 7.5, 10 and 15 t ha^{-1}. The treatments viz., T_1: Absolute control, T_2: RDF alone, T_3: RPP, T4: RPP + Maize cob rind biocharat 7.5 t ha^{-1}, T_5: RPP + Maize cob rind biochar at10 t ha^{-1},T_6: RPP + Maize cob rind biochar at 15 t ha^{-1}, T_7: RPP + *Prosopis sps* biochar at7.5 t ha^{-1}, T8: RPP + *Prosopis sps* biochar at10 t ha^{-1}, T_9: RPP + *Prosopis sps* biochar at 15 t ha^{-1}, T_{10}: RPP + Coconut shell biochar at 7.5 t ha^{-1}, T_{11}: RPP + Coconut shell biochar at10 t ha^{-1} and T_{12}: RPP + Coconut shell biochar at 15 t ha^{-1}.The recommended dose of fertilizer ($N:P_2O_5:K_2O$ at 100:50:30 kg ha^{-1}) was applied commonly to all the treatments except absolute control. FYM was not applied to T_4 to T_{12} treatments. The treatments were imposed in factorial randomized complete block design (RCBD) design with three replications. The experiment was conducted during kharif 2022 with maize hybrid NK6240 plus as a test crop.

The biochar and FYM were applied and incorporated in to the soil according to treatment details 20 days before sowing. The recommended dose of phosphorus, potassium was applied as SSP, muriate of potash along with zinc sulphate and iron sulphate during the sowing time and only 50 per cent of recommended nitrogen was supplied through urea at the time of sowing, remaining 50 per cent dose at tasseling stage was applied. The maize seeds were sown in each plot with a spacing of 60 cm in between the rows and 20 cm in betweenthe plants.

2.1 Characterization of Biochar

Biochar sources were procured from relevant sources and were analysed for various physico-chemical characteristics and nutrient composition by adopting standard analytical.

2.2 Statistical Analysis

The statistical analysis and interpretation of data were done using the Fischer's method of analysis of variance technique as described by Gomez and Gomez [6]. The level of significance used in 'F' test was P = 0.05. Critical difference values were calculated between various treatments wherever the 'F' test was found significant.

3. RESULTS AND DISCUSSION

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads:

3.1 Characterization of Biochar Sources

The pH values of maize cob rind biochar (8.50), *Prosopis sps* biochar (8.15) and coconut shell biochar (9.05) were alkaline in reaction. Similarly, electrical conductivity values were also slightly higher (2.72, 2.41 and 1.72 for maize cob rind biochar, *Prosopis sps* and biochar coconut shell biochar, respectively) than FYM (7.60). Increased pH and EC of biochar sources resulted from pyrolysis induced ash, causing alkalinity. Contributing factors include alkaline earth metals, alkali carbonates, silica, heavy metals, sesquioxides, phosphates, and minor organic or inorganic nitrogen. Among the different sources, *Prosopis sps* biochar had a higher amount of total carbon (78.23 g kg^{-1}) followed by the coconut shell biochar (76.07 g kg^{-1}) and maize cob rind biochar (78.23 g kg^{-1}). Correspondingly, the C:N ratio values were 124.17 (*Prosopis sps* biochar), 134.84 (coconut shell biochar) and 166.83 (maize cob rind biochar). This carbon-rich composition is a key feature of biochar, contributing to its unique properties. The major constituents of biomass (C, H and O) volatilize during dehydration and pyrolysis with H and O being lost in proportionally greater amounts than C. The pyrolytic process transforms biomass into a stable form of carbon, preventing the release of carbon dioxide into the atmosphere and effectively sequestering carbon in the biochar matrix. This was also confirmed by the study conducted by Karthik [7] reported that higher pH and EC could be the result of more processing time during pyrolysis due to woody nature of the material while compared to crop residues. According to Lee *et al*. [8] it was emphasised that dry biomass with high carbon content would result in greater carbon content in the biochar after pyrolysis.

Prosopis sps biochar recorded higher amounts of nutrients, N (0.63 %), P (0.37 %), K (2.43 %), Mg (1.20 %) and S (0.29 %) than coconut shell biochar (N- 0.56 %, P- 0.29 %, K- 1.80 %, Mg- 0.89% and S- 0.23 %) and maize cob rind biochar (N- 0.42 %, P- 0.23 %, K- 1.25 %, Mg- 0.70 % and S- 0.18 %). But, higher amount of Ca was recorded by coconut shell biochar (1.60 %), followed by *Prosopis sps* biochar (1.44 %) and maize cob rind biochar (1.07 %). Among the biochar sources, *Prosopis sps* biochar had relatively higher amounts of micro nutrients, whereas maize cob rind biochar registered lower values. The variability in nutrient composition can be attributed to different feedstocks and different conditions under which the various biochars were manufactured. Schmidt and Noack [9] noted that the exact chemical composition of biochar was a function of the conditions during combustion, such as temperature and moisture content of the fuel. Egamberdieva *et al.* [10] observed variation in nutrients composition in biochars prepared using maize two different pyrolysis techniques *i.e,* heating at 600˚C for 30 minutes and batch wise hydrothermal carbonization at 210˚C for 8 hours. In the present investigations it was observed that the major and minor nutrient contents were more in *Prosopis sps* biochar followed by coconut shell biochar and maize cob rind biochar. The superiority in nutrient composition of *Prosopis sps* biochar over other biochars was confirmed by Shenbagavalli and Mahimairaja (2012).

Table 1. Initial physical chemical and biological properties of the experimental soil

Sl. No.	Properties of soil	Values
Physical		
1.	Particle size distribution (%)	
	a. Sand	27.50
	b. Silt	17.50
	c. Clay	55.0
2.	Texture	Clay
3.	Bulk density (Mg m^{-3})	1.25
4.	MWHC (%)	62.40
Chemical		
5.	pH (1:2.5 soil: water suspension)	7.33
6.	EC (1:2.5 soil: water extract) (dSm^{-1})	0.20
7.	Organic carbon (g kg^{-1})	4.50
8.	Available nitrogen (kg ha^{-1})	113.00
9.	Available P_2O_5 (kg ha^{-1})	38.50
10.	Available K_2O (kg ha^{-1})	538.00
11.	Exchangeable calcium (c mol(p+) kg^{-1})	28.00
12.	Exchangeable magnesium (c mol(p+) kg^{-1})	18.00
13.	Available sulphur (mg kg^{-1})	16.00
14.	DTPA Fe (mg kg^{-1})	4.69
15.	DTPA Mn (mg kg^{-1})	5.25
16.	DTPA Zn (mg kg^{-1})	0.55
17.	DTPA Cu (mg kg^{-1})	2.10
18.	$CaCO_3$ equivalent (g kg^{-1})	97.50
19.	Cation exchange capacity (c mol(p+) kg^{-1})	55.63

Table 2. Physico-chemical properties and nutrient composition of different sources ofbiochar

Sl. No.	Particulars	Maize cob Biochar	*Prosopis sps* Biochar	Coconut shell Biochar
Physico-chemical properties				
1.	Bulk density (Mg m^{-3})	0.43	0.45	0.40
2.	MWHC (%)	65.00	62.00	61.00
3.	pH (1: 5)	8.50	8.15	9.05
4.	EC (1: 5) (dS m^{-1})	2.72	2.41	1.72
Nutrient composition				
5.	Carbon (%)	70.07	78.23	76.07
6.	Nitrogen (%)	0.42	0.63	0.56
7.	C : N (ratio)	166.83	124.17	135.84
8.	Phosphorus (%)	0.23	0.37	0.29
9.	Potassium (%)	1.25	2.43	1.80

3.2 Growth Parameters of Maize

Plant height, leaf area and total dry matter of maize observations were carried out at harvest of maize crop. The analysis of variance showed that the application of biochar sources at different levels and their interaction had significant effect on growth parametersof maize.

Among the sources, significantly higher plant height leaf area and total dry matter of 197.41 cm, 18.72 dm^2 $plant^{-1}$ and 188.21 g $plant^{-1}$, respectively was recorded with *Prosopis sps* biochar + RPP at harvest, respectively. The lower values were noticed with the application of maize cob rind biochar + RPP. Application of inorganic fertilizer and *Prosopis sps* biochar which had rich nutrient composition and high nutrient release capacity compared to other biochar sources, proved advantageous for promoting maize crop growth. The provision of abundant nutrients not only fulfils the nutritional needs of maize but also stimulates increased photosynthesis activity in turn, contributes to enhanced vegetative growth in maize. Superiority of prosopis biochar over other biochars was found similar with Karthik *et al.* [7] in cotton and Rahayu *et al.* [11] in hybrid maize.

Among the levels irrespective of sources, a significantly higher plant height, leaf area and total dry matter of 195.92 cm, 18.58 dm^2 $plant^{-1}$ and 196 g $plant^{-1}$, respectively at harvest, respectively was recorded with the application of biochars at 15 t ha^{-1} and lower was recorded with the applications of biochars at7.5 t ha^{-1} At higher application rates, biochar contributes to improved soil structure, enhanced water retention and increased nutrient availability, all of which collectively create a more favourable environment for maize development. The greater quantity of biochar appears to have a stimulatory effect on root development, nutrient uptake and overall plant growth. The beneficial effects of higher rate of biochar application on enhancing the growth of maize crop was reported by Njoku *et al.* [12] application at 15 t ha^{-1} and Coumaravel *et al.* [13] application at 19 t ha^{-1}.

The interaction effects of sources and levels of biochars showed that the highest plant height (205.11 cm), leaf area (19.45 dm^2 $plant^{-1}$) and total dry matter (207.87 g $plant^{-1}$) at harvest were obtained with the treatment application of RPP + *Prosopis sps* biochar at 15 t ha^{-1}. The lowest was recorded with application of RPP + maize cob rind biochar at 7.5 t ha^{-1}. The increased in growth parameters in response to application of different types of biochar with combination of inorganic fertilizers is probably due to enhanced availability of nitrogen which enhanced more leaf area resulting in higher photo assimilates and thereby resulted in more dry matter accumulation. The increase in growth parameters might be attributed to the adequate supply of nutrients by the biochar and fertilizer application. This was in support with the findings of Prasanna (2012), the treatment combination of 3 t ha^{-1} + RDF + FYM 10 t ha^{-1} recorded significantly higher maize crop growth might be due to supply of all the essential nutrients through biochar.

3.3 Yield and Yield Parameters

Among the sources RPP + *Prosopis sps* biochar recorded higher cob length (19.13 cm), number of kernels per row (26.80), number of kernels per cob (499.63), grain weight per cob (174.44 g cob^{-1}), grain yield (57.80 q ha^{-1}) and stover yield (92.96 q ha^{-1}) of maize compared to other sources. *Prosopis sps* biochar along with inorganic fertilizers increased plant growth and nutrient uptake optimally supported the yield parameters. As a result, the higher plant growth and yield parameters contributed directly to an increased maize yield. The abundant nutrients in *Prosopis sps* biochar promote efficient nutrient utilization, resulting in an increased overall maize crop yield. This was also confirmed with Srinivasarao *et al.* [14] that, *Prosopis* biochar was found better than rice husk biochar at all application rates in improving black gram yield at Kumulur (Trichy district) and Cornelissen *et al.* [15] concluded that maize cob biochar was found superior over wood biochar at 4 t ha^{-1} increasing maize yields.

Irrespective of sources, application of biochars at higher dosage of 15 t ha^{-1}, recorded higher yield and yield parameters of maize compared to other application levels of biochars. Biochar, when applied at a higher dosage, can enhance soil porosity and water-holding capacity, leading to improved water infiltration and retention. This, in turn, supports better root development and nutrient uptake and better partitioning of carbohydrates from leaf to reproductive parts resulting in increased yield. These findings were in support with Njoku *et al.* [12] biochar application up to 15 t ha^{-1}. Imran *et al*. [16] with 25 t ha^{-1} and Liu *et al.,* [17] with 40 t ha^{-1} of biochar application increased yield of maize crop. Significant differences were also observed with respect to interaction effects of various sources and levels of biochar application. A significantly higher yield and yield parameters of maize compared to other application levels of biochars obtained with the treatments RPP + *Prosopis sps* biocharat 15 t ha^{-1} compared to other biochar applied treatments. Addition of more nutrients through biochar and inorganic fertilizers resulted in higher grain and stover yield in maize could be attributed to better total uptake of essential nutrients and its translocation to economic parts as well as improvement in yield attributing characters like cob weight, cob length and number of kernels per cob. Gokila [18] application of biochar with inorganic fertilizers and Azophos biofertilizer increased the yield components of maize. Shivshankar [19] recorded higher grain and straw yield of maize, with the application of 125 per cent RDN + farm waste biochar at 5.0 t ha^{-1} [20-22].

Table 3. Effect of sources and levels of biochar on growth parameters of maize at harvest

Treatments	Plant height (cm)				Leaf area (dm^2 plant^{-1})				Total dry matter (g plant^{-1})			
	At harvest											
S / L	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
S_1	173.04^{c}	184.14^{a-c}	187.14^{a-c}	181.44^{b}	16.41^{c}	17.46^{a-c}	17.74^{a-c}	17.20^{b}	159.53^{d}	171.58^{b-d}	184.79^{a-c}	171.97^{b}
S_2	185.47^{a-c}	201.64^{ab}	205.11^{a}	197.41^{a}	17.59^{a-c}	19.12^{ab}	19.45^{a}	18.72^{a}	174.05^{b-d}	182.71^{b-d}	207.87^{a}	188.21^{a}
S_3	179.00^{bc}	191.48^{a-c}	195.50^{a-c}	188.66^{ab}	16.97^{bc}	18.16^{a-c}	18.54^{a-c}	17.89^{ab}	165.00^{cd}	176.58^{b-d}	195.30^{ab}	178.96^{ab}
Mean	179.17^{b}	192.42^{a}	195.92^{a}		16.99^{b}	18.25^{a}	18.58^{a}		166.19^{b}	176.96^{b}	196.00^{a}	
C_1	167.54				15.89				150.86			
C_2	172.22				16.33				157.74			
C_3	182.18				17.27				169.17			
S. V*	**S.Em ±**		**C.D at 5 %**		**S.Em ±**		**C.D at 5 %**		**S.Em ±**		**C.D at 5 %**	
S	4.16		-		0.03		-		4.24		-	
L	4.16		-		0.03		-		4.24		-	
S x L	7.20		-		0.057		-		7.34		-	
Control	7.72		22.79		0.61		0.18		7.59		22.39	

**Source of variation*

Note:

C_1 = Absolute control	S_1 = RPP + Maize cob rind biochar	L_1 = 7.5 t ha^{-1}
C_2 = RDF	S_2 = RPP +*Prosopis sps* biochar	L_2 = 10 t ha^{-1}
C_3 = RPP	S_3 = RPP + Coconut shell biochar	L_3 = 15 t ha^{-1}

Table 4. Effect of sources and levels of biochar on total dry matter production, yield and yield parameters of maize at harvest

Treatments	Cob length (cm)				Number of kernels per row				Number of kernels per cob			
S / L	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
S_1	16.78^{b}	17.46^{b}	18.04^{ab}	17.40^{b}	22.53^{d}	24.10^{cd}	26.20^{a-d}	24.28^{b}	403.81^{d}	433.95^{cd}	490.42^{bc}	442.73^{b}
S_2	17.97^{ab}	19.04^{ab}	20.29^{a}	19.13^{a}	24.22^{cd}	26.89^{a-c}	29.29^{a}	26.80^{a}	433.95^{cd}	502.63^{b}	562.31^{a}	499.63^{a}
S_3	17.24^{b}	18.60^{ab}	19.15^{ab}	18.33^{ab}	23.16^{d}	25.29^{b-d}	28.29^{ab}	25.58^{ab}	413.35^{d}	461.08^{b-d}	516.60^{ab}	463.68^{b}
Mean	17.35^{b}	18.78^{a}	18.72^{a}		23.30^{c}	25.42^{a}	27.93^{a}		417.04^{c}	465.89^{b}	523.11^{a}	
C_1	15.82				13.09				218.74			

Treatments	**Cob length (cm)**				**Number of kernels per row**				**Number of kernels per cob**			
C_2	16.53				21.36				363.90			
C_3	17.10				24.56				440.40			
S. V.	**S.Em ±**		**C.D at 5 %**		**S.Em ±**		**C.D at 5 %**		**S.Em ±**		**C.D at 5 %**	
S	0.42		-		0.64		-		11.72		-	
L	0.42		-		0.64		-		11.72		-	
S x L	0.73		-		1.11		-		20.30		-	
Control	0.76		2.25		1.07		3.15		19.18		56.61	
	Grain weight per cob (g cob^{-1})				**Grain yield (q ha^{-1})**				**Stover yield (q ha^{-1})**			
S / L	**L_1**	**L_2**	**L_3**	**Mean**	**L_1**	**L_2**	**L_3**	**Mean**	**L_1**	**L_2**	**L_3**	**Mean**
S_1	138.79^{d}	160.43^{b-d}	171.16^{a-c}	156.79^{b}	45.83^{d}	52.43^{cd}	60.02^{ab}	52.76^{b}	65.48^{c}	73.75^{a-c}	85.92^{a-c}	75.82^{c}
S_2	157.75^{cd}	171.18^{a-c}	194.40^{a}	174.44^{a}	50.55^{cd}	56.37^{bc}	66.49^{a}	57.80^{a}	75.0^{a-c}	82.64^{a-c}	92.96^{a}	83.53^{a}
S_3	142.16^{d}	168.16^{bc}	183.50^{ab}	164.61^{ab}	49.46^{cd}	54.71^{bc}	61.70^{ab}	55.29^{b}	68.82^{bc}	79.90^{a-c}	88.11^{ab}	78.94^{b}
Mean	146.23^{c}	166.59^{b}	183.02^{a}		48.61^{c}	54.51^{b}	62.74^{a}		69.77^{c}	78.76^{b}	88.99^{a}	
C_1	70.31				36.34				50.24			
C_2	102.24				42.80				60.32			
C_3	156.36				48.81				69.01			
S. V.	**S.Em ±**		**C.D at 5 %**		**S.Em ±**		**C.D at 5 %**		**S.Em ±**		**C.D at 5 %**	
S	4.17		-		1.31		-		1.00		-	
L	4.17		-		1.31		-		1.00		-	
S x L	7.23		-		2.27		-		1.74		-	
Control	6.72		19.84		2.24		6.60		2.07		6.10	

*Source of variation

Note:

C_1 = Absolute control	S_1 = RPP + Maize cob rind biochar	L_1 = 7.5 t ha^{-1}
C_2 = RDF	S_2 = RPP +*Prosopis sps* biochar	L_2 = 10 t ha^{-1}
C_3 = RPP	S_3 = RPP + Coconut shell biochar	L_3 = 15 t ha^{-1}

4. CONCLUSION

The study revealed that application of *Prosopis sps* biochar at15 t ha^{-1} significantly increased the growth, yield and quality parameters of maize while it was comparable with coconut shell biochar at 15 t ha^{-1}. Hence, biochars applying to the soil as amendment enhances soil health and fertility along with increase in yield of crops. It provides sustainable solution to the farmers by preventing burning of crop residues in the field. In addition, chelation effect of biochar reduces leaching losses of applied fertilizers thereby reduction in pollution.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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