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Influence of Biochar Prepared from Different Crop Residues on Soil Properties and Yield of Maize

Sakshi Dipak Wandhare*, G. S. Laharia, S. M. Bhoyar, S. D. Jadhao and M. N. Gawande

Department of Soil Science, Dr. PDKV, Akola - 444104, M.S., India

**Corresponding author*

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A B S T R A C T

The field and laboratory study entitled, "Influence of biochar prepared from different crop residues on soil properties and yield of maize" was conducted on the Research Farm, Agriculture Technical School, Buldhana, Dr. PDKV, Akola during *Kharif*,2023-24. The experiment was laid out in a Factorial Randomized Block Design (FRBD) with seven treatments and three replications. The treatments comprised of Factor A including biochar levels (2.5 and 5.0 tha^{-1}) and Factor B including biochar sources i.e sorghum stubble, pigeon pea stalk and cotton stalk with control (without biochar). Based on the result obtained biochar prepared from pigeon pea stalk was recorded highest total NPK content (0.61%, 0.25%, 1.32% respectively), whereas highest total carbon content (36.38%) was recorded in cotton stalk biochar. whereas highest C:N ratio (64.96) was recorded in cotton stalk biochar. Soil physical properties like lower bulk density (1.38 Mg m^{-3}) and higher hydraulic conductivity (0.65 cm hr^{-1}, water holding capacity (61.58%) as well as available NPK(253.02, 18.32, and 393 kg ha^{-1} respectively in the soil after harvest of maize were recorded significantly highest with the application of biochar@ 5tha^{-1} and the treatment with different sources of biochar was found non-significant but lower bulk density(1.39 dSm^{-1}) and highest hydraulic conductivity (0.67 cm hr^{-1}), water holding capacity (60.36 %) as well as available NPK (260.04, 17.80, 390 kgha^{-1}) were g observed in pigeon pea stalk biochar. Incase of organic carbon (6.30 g kg^{-1}), significantly highest values were recorded with the application of biochar @5tha^{-1} and the treatment with different biochar sources was found non-significant but the highest organic carbon (6.20 g kg^{-1}) was observed in cotton stalk biochar. Application of biochar @5 tha^{-1}prepared from pigeon pea and cotton stalk recorded high grain yield (90.15 q ha^{-1}) and stover yield (129.40 q ha^{-1}).

Introduction

Crop waste management is a significant problem in the agricultural sector. Every year, millions of tons of crop residue are produced around the world. Most crop residues are burned or abandoned directly in the field releasing harmful gases, smog, and particulate matter into the atmosphere. In many regions, crop residue burning is a major contributor to air pollution because there is no viable way to dispose of crop residue. One of the serious issues facing the world today is climate change, which is becoming a significant threat to our earth. Increasing global warming adversely affects agricultural development, including extreme weather disasters, drought, and soil erosion. Therefore, an effective and environmentally friendly solution for agro-residue disposal is required. The conversion of agro residue to biochar could be one of the techniques for safely disposing of it and has gained significant scientific attention as a potential solution to these issues. A carbon-rich substance called biochar is created by thermochemically converting lignocellulosic biomass, such as woody biomass, agricultural wastes, organic waste, and municipal garbage (Wang and Wang, 2019; Rathod *et al.,* 2023).

The most widely used method for creating biochar is called pyrolysis, a thermochemical procedure in which an organic feedstock is broken down under anaerobic conditions at a temperature (~350-600°C) or with little to no oxygen present (Panwar *et al.,* 2019; Patel *et al.,* 2021). The characteristic features of biochar are its large surface area, rich carbon content, highly porous structure, recalcitrant and high cation exchange capacity, which are the reasons for its use in environmental applications such as carbon sequestration soil amendment and water treatment. Based on these properties, biochar reduces soil organic carbon decomposition by 44 to 365 kg C/t BC-C and improves carbon capture by plants. Biochar is a useful tool for environmental remediation due to its capacity to absorb and catalyse a wide range of organic and inorganic contaminants found in wastewater. Biochar produced from crop residue is a product of the inexhaustible-energy-focused thermochemical conversion technology, which produces biochar to replace chemical fertilizer and control the in-situ burning of crop waste (Gupta *et al.,* 2020). Freshly cropped biomass, including agricultural plant and forest residues, sewage sludge, algae, animal manure, etc., typically contains more than 30% of water.

They are referred to as wet biomass. Agricultural wastes with a water content below 30% are classified as dry feedstock. Wet biomass can be pre-dried using technologies developed for drying other biomaterials. However, in most cases, such technologies are labour-consuming and decrease the total economic effect of biochar application. Biomass is classified on that specially harvested as bioenergy crops (bamboo, sorghum, willows, Miscanthus, switch grass and agricultural wastes.

Maize, (*Zea mays L)* commonly known as corn, is a staple crop that is widely cultivated across the world. Belonging to the grass family Poaceae, it has gained popularity due to its adaptability and wide acceptance. Maize is a cereal crop that is grown for its kernels, which can be processed into various food products. Maize grain is a rich source of nutrients, containing approximately 10-12% protein, 4% oil, 0.5% fibre, 1.5% fat, 66.2% carbohydrates and 2.75% minerals. Additionally, it is a good source of vitamins A, nicotinic acid, riboflavin and vitamin E. The presence of vitamins A, C and K, along with beta-carotene and selenium, helps to improve the immune system. Green fodder, on the other hand, contains about 5% protein, 6% minerals, 4.3% fats, and 52.8% carbohydrates. In India, the majority of maize production (approximately 35%) is used for human consumption, while 47% is used for poultry feed, 13% for livestock feed, 12% for industrial purposes, 14% for the starch industry, and 6% for export and other uses. According to 2023-2024 the production is now estimated to be at 28 million MT. In India, maize is principally grown in two seasons, monsoon (*Kharif*) and winter (*rabi*). *Kharif* maize represents around 83% of maize area in India, while *rabi* maize correspond to 17% maize area.

Materials and Methods

The field experiment was conducted on the Research Farm, Agriculture Technical School, Buldhana, Dr. PDKV, Akola during *Kharif*, 2023-24. The experiment was laid out in a Factorial Randomized Block Design (FRBD) with seven treatments and three replications. The treatments comprised of control, different levels with 2.5 tha^{-1} and 5.0 tha^{-1} of biochar and sources with sorghum stubble, pigeon pea stalk and cotton stalk biochar. Biochar was applied at rates of 2.5 and 5.0 tha^{-1} one week before sowing of maize crop, according to the respective treatments. Control treatments without the application of biochar were also maintained. At the time of sowing, the recommended dose of inorganic chemical fertilizers was applied. Nitrogen was applied as per treatments as a basal dose and at 30 DAS in the form of urea (46%). A full dose of single super phosphate (16% P_2O_5) and muriate of potash (60% K_2O) was applied to all the treatments according to the recommended dose of fertilizers (120:60:60 NPK kg ha^{-1}). Various parameters of the biochar were analyzed using the methods and the results were used for field application. pH and EC were determined using pH and conductivity meter as described by Jackson (1973), total carbon by dry combustion method (Batjes, 2005), Total N content was determined by Micro-Kjeldahl's distillation method (Keeny and Nelson, 1982), Total P was determined by Modified procedure of Change and Jackson method using spectrophotometer (Peterson and Corey, 1966).

Total K content was determined by triacid method i.e., H_2SO_4, $HClO_4$ and HF digestion in 9:4:1 ratio as given by Jackson (1973). C:N ratio was determined by Dry Combustion method: Micro- Kjeldahl method as described by Batjets (2005) and Keeny and Nelson (1982). Bulk density was determined by using the clod coating method by Blake and Hartage (1986), Maximum water-holding capacity of the soil was determined by Keen Reckzonski boxes as described by Gupta and Dakshinamoorthi (1980). Hydraulic conductivity of soil was determined by Constant Head Method (Klute and Dirksen, 1986). Organic carbon was determined by wet oxidation method (Nelson and Sommers, 1982), Available nitrogen content in soil was determined by alkaline potassium permanganate method (Subbiah and Asija, 1956), Available phosphorus in soil was determined by Olsen's method (Watanabe and Olsen, 1965), Available potassium in soil was determined by neutral normal ammonium acetate method (Jackson, 1973).

Results and Discussion

Chemical composition of biochar

The chemical composition of biochar indicates that the pH values of sorghum stubble biochar (8.3), pigeon pea stalk biochar (8.8), and cotton stalk biochar (8.59) are alkaline. The EC values are 1.2, 1.5, and 1.32 dSm^{-1} for sorghum stubble biochar, pigeon pea stalk biochar, and cotton stalk biochar, respectively.

Total NPK content (0.61, 0.25 and 1.32% respectively) was recorded highest in pigeon pea stalk biochar. The highest total carbon content at 36.38 g kg^{-1} and C:N ratio (64.96) was recorded in cotton stalk biochar.

This was also confirmed by a study conducted by Reyhanitabar *et al.,* (2020); Naeem *et al.,* (2014). The pH, electrical conductivity (EC) and carbon content of biochars increased significantly with increasing temperature. Omotade *et al.,* (2020), investigated the changes in the nutrient composition of biochars that were prepared and pyrolyzed at four different temperatures: 300, 400, 500, and 600 °C.

Physical properties of soil after harvest of maize

Effect of biochar levels

Application of different levels of biochar had a notable impact on soil bulk density, water holding capacity and hydraulic conductivity after the harvest of crop as indicated in table 2 and Fig 1. Significantly lower bulk density (1.38 Mg m^{-3}), higher water holding capacity (56.58%) and hydraulic conductivity (0.65 $cmhr^{-1}$) were recorded in application of biochar@ 5tha^{-1}(L_2)over application of biochar@ 2.5 tha^{-1} (L_1) led to a higher bulk density of (1.40 Mg m^{-3}), low water holding capacity (53.75%) and hydraulic conductivity (0.64 cm hr^{-1}). This is due to the high porosity of biochar when applied to the soil, reduces soil bulk density by increasing pore volume, creating a more porous and less dense soil environment. According to Aslam *et al.,* (2014), the application of biochar at a rate of 1-2% (W/W) has been found to decrease soil bulk density. And biochar application has been shown to increase the water-holding capacity of the soil. Tokova *et al.,* (2020) studied that biochar was applied at the rates of 0, 10 and 20 tha−1 and the values of saturated hydraulic conductivity (K) increased with an increasing application rate of biochar.

Effect of biochar sources

The application of various biochar sources does not showed a significant impact on soil bulk density after the crop harvest. The application of sorghum stubble biochar (S_1) and the pigeon pea stalk biochar (S_2) resulted in the lowest bulk density (1.39 dSm^{-1}) and the application of pigeon pea stalk biochar (S_2) demonstrated the highest water holding capacity (55.87%) and hydraulic conductivity (0.67 cm hr^{-1}) whereas the application of cotton stalk biochar (S_3) exhibited a higher bulk density (1.4 dSm^{-1}), and application of sorghum stubble biochar (S_1) exhibited a lower WHC (54.33%) and hydraulic conductivity (0.65 $cmhr^{-1}$) although these differences were determined to be statistically non-significant. In a study by Aslam *et al.,* (2014), it was found that the application of different sources of biochar reduces soil bulk density. Additionally, biochar application was shown to increase the water holding capacity of the soil. According to Lei and Zhang (2013), Biochars were produced with dairy manure and woodchip at temperatures of 300, 500, and 700 °C, respectively. The treatments with woodchip biochars resulted in higher saturated hydraulic conductivities than the dairy manure biochar treatments.

Interaction effect

Results of the study show that there was no statistically significant relationship between the various levels of biochar and the types of sources on bulk density, hydraulic conductivity and water holding capacity (WHC) of the soil after the maize harvest.

The data presented in the table 3, indicated that the treatment combination of biochar levels and sources was not statistically significant. Specifically, in treatment combinations pigeon pea stalk biochar @ 5 t ha^{-1} (L_2S_2) and cotton stalk biochar @ 5 t ha^{-1} (L_2S_3), recorded low bulk density (1.38 Mgm-3). The treatment combination pigeon pea biochar @ 5 tha^{-1} (L_2S_2) exhibited the highest WHC (57.36%) and hydraulic conductivity (0.68 cmhr^{-1}).

The data further revealed that the lower bulk density, high water holding capacity and hydraulic conductivity of all the treatment combinations were recorded highest as compared to control (L_0S_0). Burrell *et al.,* (2016) found that the application of biochar led to a decrease in soil physical properties such as bulk density in all treatments compared to the control treatment, while water holding capacity (WHC) increased. Tokova *et al.,* (2020) reported that the values of saturated hydraulic conductivity (K) increased with an increasing application rate of biochar in most of the treatments with or without fertilization (N0, N1 and N2).

Effect of biochar on chemical properties of soil after harvest of maize

Effect of biochar levels

The data presented in Table 4. illustrates the impact of various levels of biochar on soil pH, EC and organic carbon after the maize harvest. The application of 5 tha^{-1} of biochar (L_2) resulted in the highest pH (7.88), EC(0.29 dSm^{-1}) but the result was found statistically non-significant. In the case of organic carbon, significantly highest values (6.30 g kg^{-1}) were recorded in application of biochar@ 5 tha^{-1} whereas the lowest values of pH(7.86), EC(0.28) and organic carbon(5.80 g kg^{-1}) were recorded with application of biochar @ 2.5 t ha^{-1}. Khalil *et al.,* (2023) studied that, a higher biochar application rate (i.e. 5%) significantly ($P < 0.05$) increase chemical properties, i.e. EC and pH. Chen *et al.,* (2024), study aimed to determine the impact of different types and rates of biochar applied in tropical farmlands on SOC. The results showed that Soil organic carbon content increased with increasing biochar application rates.

Effect of biochar sources

Application of pigeon pea stalk biochar (S_2) and cotton stalk biochar (S_3) recorded high pH (7.88) and EC (0.29 dS m^{-1}) as compared to application of sorghum stubble biochar (S_1) pH (7.86) and EC (0.28 dS m^{-1}) whereas the application of cotton stalk biochar (S_3) recorded highest organic carbon (0.62 g kg^{-1}), followed by the application of pigeon pea stalk biochar (S_2) 0.60 g kg^{-1}and sorghum stubble biochar (S_1) (0.59 g kg^{-1}). The study by Karthik *et al.,* (2019) found that soil pH and (EC) were higher in treatments where prosopis biochar was used compared to treatments using cotton biochar, regardless of the quantity applied. This is likely due to the higher pH of Prosopis biochar (8.70), which raised the pH of the soil. Similar findings were reported by Pandian *et al.,* (2016) and Utomo *et al.,* (2017). Additionally, biochar application increased the soil EC.

Interaction effect

The study's findings revealed that after the maize harvest, the combined influence of different levels and sources of biochar on soil pH, electrical conductivity and organic carbon of soil was found to be statistically non-significant.

Based on the data presented in the table5, it was evident that the treatment combination involving different levels and sources of biochar did not show any statistically significant difference. Specifically, the combinations pigeon pea stalk biochar@5 tha^{-1}(L_2S_2) and cotton stalk biochar @ 5tha^{-1} (L_2S_3) exhibited high pH (7.88) and organic carbon (OC) (0.61gkg^{-1}).

Combination cotton stalk biochar @ 5tha^{-1}(L_2S_3) demonstrated a higher (EC) (0.30dSm^{-1}) compared to other combinations. Chintala *et al.,* (2013) concluded that pH and EC of soil were increased with the application of biochar as compared to control.

An experiment of different application rates of biochar and biochar combined with nitrogen fertiliser was conducted at the experimental field. The results showed that SOC was always higher at the plots amended with biochar as compared to control plots this was concluded by Horak and Simansky (2016).

Table.1 Chemical composition of biochar prepared from different crop residues.

Properties	Sorghum stubble	Pigeon pea stalk	Cotton stalk
pH	8.3	8.8	8.59
EC	1.20	1.50	1.32
Total C	32.20	35.52	36.38
Total N	0.52	0.61	0.56
Total P	0.21	0.25	0.23
Total K	1.29	1.32	1.30
C:N ratio	61.92	58.23	64.96

Table.2 Physical properties of soil after as influenced by various treatments

Treatments	Bulk Density (Mg m^{-3})	HC (cm hr^{-1})	WHC (%)
Biochar levels			
L_1 – Biochar @ 2.5 t ha^{-1}	1.40	0.64	53.75
L_2 - Biochar @ 5.0 t ha^{-1}	1.38	0.65	56.58
S E (m) ±	0.006	0.006	1.04
CD at 5%	0.02	0.017	3.11
Biochar Sources			
S_1- Sorghum stubble	1.39	0.65	54.33
S_2- Pigeon Pea Stalk	1.39	0.67	55.87
S_3- Cotton Stalk	1.40	0.63	55.29
S E (m) ±	0.003	0.005	0.31
CD at 5%	-	-	-
Interaction Biochar Levels X Sources			
SE (m) ±	0.003	0.008	1.03
CD at 5%	-	-	-

Table.3 Interaction effect of levels and sources of biochar on physical properties of soil

Treatment combinations (L X S)	BD (Mg m^{-3})	HC (Cm hr^{-1})	WHC (%)
L_1S_1	1.40	0.64	53.30
L_1S_2	1.40	0.66	54.39
L_1S_3	1.41	0.62	53.57
L_2S_1	1.39	0.65	55.36
L_2S_2	1.38	0.68	57.36
L_2S_3	1.38	0.63	57.02
SE (m) ±	0.0067	0.008	1.36
CD at 5%	-	-	-
Control Vs other treatments			
L_0S_0	1.43	0.61	47.55
SE (m) ±	0.012	0.008	1.60
CD at 5 %	0.030	0.018	3.20

Table.4 Chemical properties of soil after harvest of maize as influenced by various treatments

Treatments	pH	EC (dS m^{-1})	OC (g kg^{-1})
Biochar levels			
L_1 – Biochar @ 2.5 t ha^{-1}	7.86	0.28	5.80
L_2 - Biochar @ 5.0 t ha^{-1}	7.88	0.29	6.30
SE (m) ±	0.01	0.003	0.15
CD at 5%	-	-	0.48
Biochar Sources			
S_1- Sorghum stubble	7.86	0.28	5.90
S_2- Pigeon Pea Stalk	7.88	0.29	6.00
S_3- Cotton Stalk	7.88	0.29	6.20
SE (m) ±	0.001	0.003	0.10
CD at 5%	-	-	-
Interaction Biochar Levels X Sources			
SE (m) ±	0.01	0.014	0.13
CD at 5%	-	-	-

Table.5 Interaction effect of levels and sources of biochar on chemical properties of soil

Treatment combinations (L X S)	pH	EC (dS m^{-1})	OC (g kg^{-1})
L_1S_1	7.86	0.28	5.8
L_1S_2	7.86	0.28	5.8
L_1S_3	7.87	0.29	5.9
L_2S_1	7.87	0.29	0.60
L_2S_2	7.88	0.29	0.61
L_2S_3	7.88	0.30	0.61
SE (m) ±	0.006	0.006	0.006
CD at 5%	-	-	-
Control Vs other treatments			
L_0S_0	7.84	0.26	5.6
SE (m) ±	0.003	0.006	0.006
CD 5 %	0.011	0.021	0.022

Table.6 Available NPK status of soil as influenced by various treatments

Treatments	Available nutrients (kg ha^{-1})		
	Nitrogen	phosphorus	potassium
Biochar levels			
L_1 - Biochar @ 2.5 tha^{-1}	248.83	15.40	376
L_2 - Biochar @ 5.0 tha^{-1}	253.02	18.32	393
S E (m) ±	1.46	1.06	1.27
CD at 5%	4.40	3.19	3.85
Biochar Sources			
S_1- Sorghum stubble	238.90	15.84	377
S_2-Pigeon Pea Stalk	260.04	17.80	390
S_3-Cotton Stalk	253.85	16.85	387
S E (m) ±	0.146	1.19	1.04
CD at 5%	-	-	-
Interaction Biochar Levels X Sources			
SE (m) ±	1.42	1.16	1.05
CD at 5%	-	-	-

Table.7 Interaction effect of levels and sources of biochar on available NPK status of soil

Treatment combinations (L X S)	Available nutrients (kg ha^{-1})		
	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})
L_1S_1	241.52	14.22	367
L_1S_2	258.62	16.24	378
L_1S_3	252.36	15.55	382
L_2S_1	245.28	17.45	387
L_2S_2	261.45	19.35	395
L_2S_3	255.34	18.15	398
SE (m) ±	2.33	1.72	9.88
CD at 5%	-	-	-
Control Vs other treatments			
L_0S_0	238.55	13.65	363
SE (m) ±	0.97	0.18	0.94
CD at 5 %	2.90	0.53	2.83

Table.8 Grain and stover yield of maize as influenced by various treatments

Treatments	Maize yield (q ha^{-1})	
	Grain	Stover
Biochar levels		
L_1 - Biochar @ 2.5 t ha^{-1}	86.76	116.06
L_2 - Biochar @ 5.0 t ha^{-1}	90.15	129.40
S E (m) ±	1.14	4.46
CD at 5%	3.41	13.37
Biochar Sources		
S_1- Sorghum stubble	87.14	115.36
S_2-Pigeon Pea Stalk	89.91	126.99
S_3-Cotton Stalk	88.32	125.23
SE (m) ±	0.53	3.88
CD at 5%	-	-
Interaction Biochar Levels X Sources		
SE (m) ±	1.46	4.63
CD at 5%	-	-

Table.9 Interaction effect of levels and sources of biochar on grain and stover yield of maize.

Treatment combinations (L X S)	Maize yield (q ha^{-1})	
	Grain	stover
L_1S_1	85.74	109.53
L_1S_2	88.35	119.86
L_1S_3	86.21	117.88
L_2S_1	88.55	121.20
L_2S_2	91.48	134.43
L_2S_3	90.43	132.58
SE (m) ±	1.04	6.58
CD at 5%	-	-
Control Vs other treatments		
L_0S_0	78.16	104.06
SE (m) ±	0.35	1.28
CD at 5 %	1.06	3.85

Figure.1 Bulk density (Mg m^{-3}) of soil as influenced by various treatment.

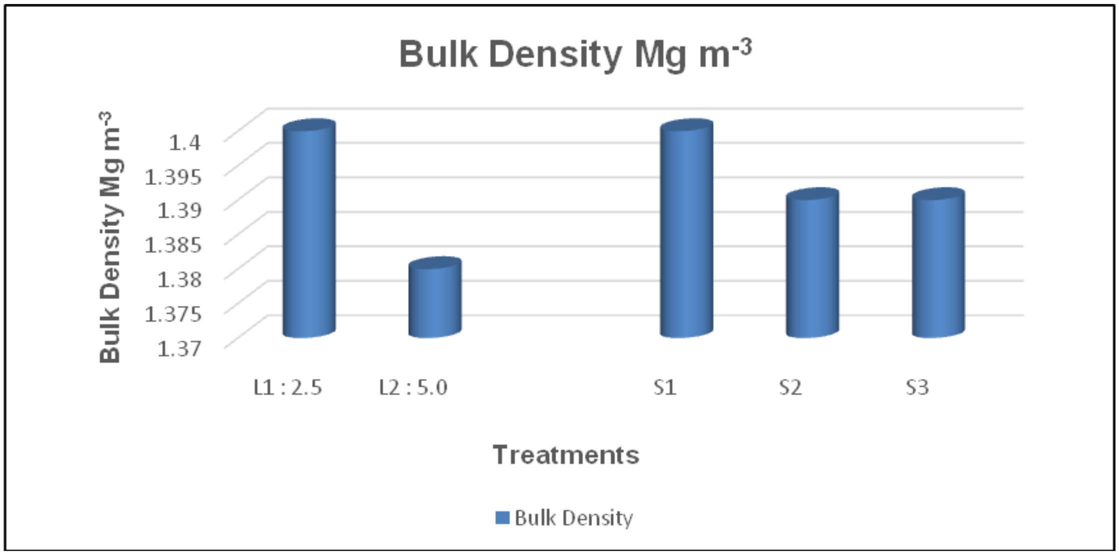
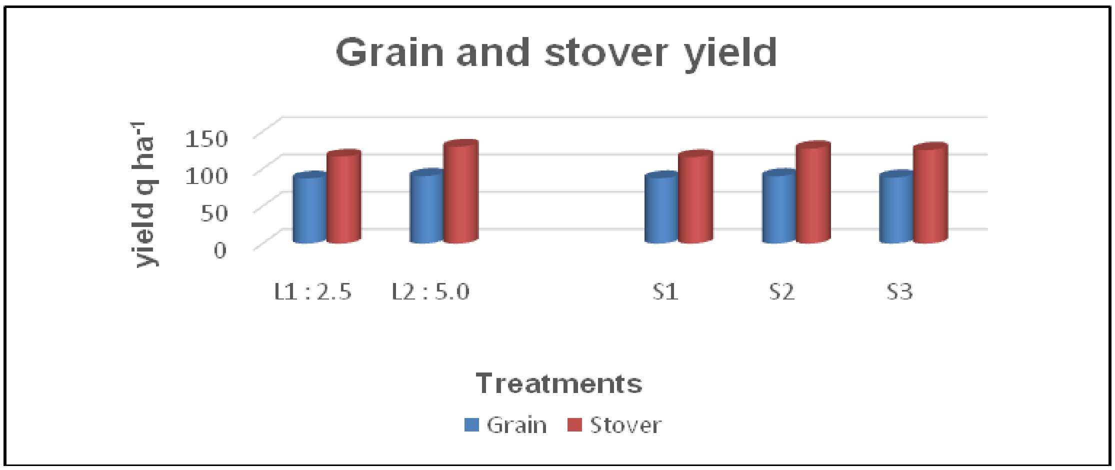


Figure.2 Grain and Stover yield of maize as influenced by various treatments



Effect of biochar on available nutrient status of soil after harvest of maize

Effect of biochar levels

In the research analysis, it was found that applying different levels of biochar had a significant impact on the availability of nitrogen, phosphorus and potassium in the soil after the maize harvest. The treatment with application of biochar at 5 tha^{-1} recorded highest available NPK (253.02, 18.32, 393 kg ha^{-1} respectively) compared to the application of biochar @ 2.5 t ha^{-1}, which recorded lower available nitrogen (248.83 kg ha^{-1}), phosphorus (15.40 kg ha^{-1}), potassium (376 kg ha^{-1}). In a study conducted by Abujabhah *et al.,* (2018) the application of biochar at different rates increases soil available nitrogen contents by 11.5–58.9%, indicating that the application of biochar can significantly increase the soil N content. Kong *et al.,* (2023) conducted a pot experiment to investigate the effects of biochar addition on soil nutrient status, Biochar was added to soil-grown cotton at three rates of 0, 3 and 30 t ha−1 under two P fertilizer levels of 0 and 150 kg P_2O_5 ha^{-1}, respectively.

Results showed that biochar addition had significantly positive effects on soil P availability. Li Wang *et al.,* (2018) experimented to investigate the influence of biochar application (0, 5, 10, and 25 g kg^{-1} soil) on soil K dynamics. It is concluded that biochar application could be a feasible soil amendment to improve soil K availability.

Effect of biochar sources

Treatment with pigeon pea stalk biochar (S_2) resulted in the highest available nitrogen (260.04 kg ha^{-1}), phosphorus (17.80 kg ha^{-1}) and potassium (390 kg ha^{-1}) while the treatment with sorghum stubble biochar (S_1) exhibited lower available nitrogen (238.90 kg ha^{-1}), phosphorus (15.84 kg ha^{-1}) and potassium(377 kg ha^{-1}) but the result was found to be statistically non-significant. Phillips *et al.,* (2022) conducted experiments and concluded that soils incubated with 2% biochar by mass to determine impacts on soil N-mineralization. Contrary to expectation, all the biochars increased soil N-mineralization relative to unamended soils. According to Gao *et al.,* (2019), the study on biochar effects on phosphorus (P) has proven inconsistent. The results showed that biochar applications significantly increased surface soil available P by 45%. Abdul *et al.,* (2017) study aimed to indicate that potassium levels remained high with increased biochar levels, suggesting that the addition of biochar will significantly increase K levels in soil.

Contrary to expectation, all the biochars increased soil N-mineralization relative to unamended soils. According to Gao *et al.,* (2019), the study on biochar effects on phosphorus (P) has proven inconsistent. The results showed that biochar applications significantly increased surface soil available P by 45%. Abdul *et al.,* (2017) study aimed to indicate that potassium levels remained high with increased biochar levels, suggesting that the addition of biochar will significantly increase K levels in soil.

Interaction effect

The findings from the study reveal that the statistical analysis did not show any significant results among diverse levels of biochar application and the different sources used, with regard to the availability of nitrogen, phosphorus, and potassium in the soil subsequent to the maize harvest.

The data presented in the Table 7 indicates that the treatment combinations of biochar levels and sources were not statistically significant. The treatment combinations, pigeon pea stalk biochar @ 5 t ha^{-1} (L_2S_2) recorded high available nitrogen (261.45 kg ha^{-1}), phosphorus (19.35 kg ha^{-1}) and potassium (398 kg ha^{-1}). The data further revealed that all treatment combinations of LXS (levels and sources) had higher available nitrogen, phosphorus and potassium compared to the control L_0S_0. Jing *et al.,* (2020) conducted a pot experiment and observed that the soil available P increased with the addition of biochar, and the increase over the experimental period averaged 7.9%. Similarly, Khalil *et al.,* (2023) conducted a greenhouse gas experiment in a complete randomized design comprising (1) no biochar application (control), (2) biochar applied at a rate of 10g kg^{-1}, (3) biochar (10g kg^{-1}) + elemental sulphur (2 g kg^{-1}) and (4) biochar acidified with H_2SO_4 (10g $kg^{-1)}$ the result indicates that this, in turn, significantly raised N- and K- available contents in the soil as compared to control.

Effect of Biochar on yield of maize

Effect of biochar levels

The data presented in Table 8, reveals that the effect of various levels of biochar had a significant impact on grain and stover yield of maize. Significantly highest grain yield (90.15 q ha^{-1}) and stover yield (129.40 q ha^{-1}) was recorded with application of Biochar @ 5tha^{-1} over the application of Biochar@ 2.5tha^{-1}.

Similar findings were reported by Yeboah *et al.,* (2016) where in they reported that the quantity of biochar application had pronounced effects on maize grain yields where higher application rates (5 tha^{-1}) showed superior performance to (2.5 tha^{-1}).

Effect of Biochar sources

The data presented in the Table 8 indicates the impact of using different sources of biochar on grain and stover yield of maize. The application of pigeon pea stalk biochar recorded highest grain (89.91 q ha^{-1}) and stover (126.99 q ha^{-1}) yield as compared to application with cotton stalk and sorghum stubble biochar but the result was found to be non significant.

According to Hebsur *et al.,* (2024) 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. 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 tha^{-1} along with RPP (Rock phosphate) without FYM, RPP and absolute control with three replications. Among the different biochar sources PSB recorded higher grain yield (59.60 q ha^{-1}) and Stover yield (81.22 q ha^{-1}).

Interaction effect

The statistical analysis revealed that there was no significant interaction effect observed among the various levels and sources of biochar on the grain and stover yield of maize.

Based on the data presented in the table 9, the treatment combinations involving different levels and sources of biochar did not show any statistically significant difference.

Specifically, the treatment combination pigeon pea stalk biochar @ 5 t ha^{-1} (L_2S_2) resulted in a high grain (91.48 q ha^{-1}) and stover yield (134.43 q ha^{-1}) as compared to other combinations.

Hebsur *et al.,* (2024) concluded that the different rates of biochar application, significantly increase the maize yield, 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.

From the present investigation, it can be concluded that biochar prepared from pigeon pea stalk had a high total NPK content, while biochar from cotton stalk had a high total carbon content. Soil application of RDF (120:60:60) kg ha^{-1} along with biochar @ 5tha^{-1} favourably influenced soil properties, available nutrient status of the soil and yield of maize. Hence biochar prepared from pigeon pea stalk and cotton stalk has given better performance as compared to sorghum stubble biochar on soil properties and yield of maize.

Author Contributions

Sakshi D. Wandhare: Investigation, formal analysis, writing—original draft. G. S. Laharia: Validation, methodology, writing—reviewing. S. M. Bhoyar:—Formal analysis, writing—review and editing. S. D. Jadhao: Investigation, writing—reviewing. Manisha Gawande: Resources, investigation writing—reviewing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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