

Research Article

Effect of biochar composite and organic sources on soil properties and yield of bhendi (*Abelmoschus esculentus* L.)

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Abstract

Biochar is considered as a possible and potential tool for soil fertility improvement, climate change mitigation and long term sink for atmospheric carbon dioxide. Soil application of biochar enhances the soil properties indirectly. A field experiment was conducted to evaluate the influence of organic manures viz., Farm Yard Manure (FYM), Vermicompost, Biochar, Biochar composite on soil properties, growth and yield of bhendi, *Abelmoschus esculentus* in *Somayyanur* soil series of Madurai district, Tamil Nadu. The experiment was laid out in randomized block design (RBD) with eleven treatments and three replications during the summer season (March – June) 2021 with the inclusion of inorganic fertilizers based on soil test crop response (STCR) based recommendation. Application of biochar composite (5 t ha⁻¹) along with STCR based NPK (75% STCR) increased the total carbon content in soil by 0.538 %. This, in turn, increased the available nitrogen status to 295 and 244 Kg ha⁻¹ at 40 and 70 DAS, respectively. Similarly, the available phosphorous (22.4, 19.3 Kg ha⁻¹) and potassium (344.70, 323.70 Kg ha⁻¹) status also showed a considerable increase with the same treatment. The yield attributes of bhendi viz., fruit length, girth, weight, dry matter production and yield recorded maximum values of 15.23 cm, 6.93 cm, 21.56 g, 11.9 t ha⁻¹ and 25.20 t ha⁻¹ with the combined application of biochar composite and NPK. The findings revealed that 25 % STCR based NPK could be reduced with the application of 5 t ha⁻¹ of biochar composite, which is economically an option besides promoting soil health.

Keywords: Bhendi, Biochar, Biochar composite, Total carbon, Yield

INTRODUCTION

In recent years, global warming has been a threatening issue to human life. Increasing global warming, in particular, brings a series of negative effects to agricultural development. Concerning adverse effect of climate change, it is crucial to maintain threshold levels of organic matter and physical, chemical and biological properties of soil (Jiang *et al.*, 2020). Biochar addition into the soil is recently considered as a feasible technique to increase the carbon status and soil quality. Biochar is a product of thermal decomposition of bio-

mass by a process termed as pyrolysis at oxygen-limited conditions. Biochar is carbon-rich material that significantly increases the soil's organic matter content, leading to improved soil quality (Dos santos Farias *et al.*, 2020). The use of biochar and organic and inorganic fertilizers has been reported to significantly improve microporosity, water holding capacity, and enzyme activities (Kannan *et al.*, 2021). It also increase plant available nutrients in soil (Silber *et al.*, 2010). Improvements in soil fertility and crop productivity depend mainly on the quantity of biochar used and soil types (Chen *et al.*, 2019). The improvement in crop yield is

attributed to increased nutrient availability, cation exchange capacity and water holding capacity of soil by the addition of biochar (Subedi *et al.*, 2017).

In India, *prosopis* was introduced in the late 1900's to meet the fuel requirement of the rural poor. It is a phreatotype plant widely distributed in India and has survived where other tree species fail to grow and become a nuisance to the environment. It inhibits the germination of other species seeds that present in its vicinity. It has a negative impact on native vegetation (Edrisi *et al.*, 2020) and interfere with water supply, hydrological functioning and herbivores grazing potential (Patnaik *et al.*, 2017). Complete eradication was inevitable but we can reduce the menace of *prosopis* by converting them into agriculturally important carbon rich biochar. Therefore, in this study *prosopis* based biochar was prepared and biochar composite was prepared to study the effect of biochar and inorganic fertilizers on soil nutrient availability, carbon status and yield of bhendi (*Abelmoschus esculentus* (L)) crop.

MATERIALS AND METHODS

Prosopis biochar was prepared by heating wooden biomass wherein under oxygen-limited conditions at 450°C (e.g. slow pyrolysis), thermo-chemical conversion drives off the volatile components of the biomass and stabilizes the remaining carbon into a black, highly aromatic solid. The samples of this biochar were collected from the pyrolysis stove sieved using a 2 mm sieve. The biochar composite was prepared by mixing biochar and vermicompost at equal proportion and moisturized in alternate days for 30 days at vermicompost yard of Agricultural College & Research Institute, Madurai. The manures were characterized as prescribed by Piper (1966), Pemberton (1945) and Jackson (1973) for total NPK. Total carbon content was analyzed by dry combustion method using elemental Total (TOC) analyzer (Allison *et al.*, 1965). Biochar composite was applied at two different levels viz., 2.5 and 5 t ha⁻¹ as soil application with 100 % and 75 % levels of Soil Test Crop Response (STCR) before sowing of bhendi seeds. The organic manures at recommended rates were applied evenly on their respective plots.

The field experiment was conducted during summer (March – June) 2021 at farmers field located in Kollankulam village of Madurai East block, Madurai district, Tamil Nadu. Bhendi hybrid Co-4 was used as a test crop. The experimental site is situated on 78°11' E latitude, 10°01' N longitude at 147 MSL. The soils of the experimental site belonged to Somayyanur soil series. The soil samples were collected and analyzed for pH (Potentiometry, Jackson, 1973), EC (Conductometry, Jackson, 1973), Texture (Piper, 1966), Bulk density (Gupta and Dhakshinamurthi, 1980), Alkaline KMnO₄-N

(Subhaiah and Asija, 1956), Olsen-P (Olsen *et al.*, 1954), NH₄OAc-K (Standford and English, 1949) and DTPA micronutrients (Lindsay and Norvell, 1978). The characteristics of the experimental soil, determined by standard methods, are presented in Table 2. The research experiment comprised of eleven treatments which were replicated thrice in randomized block design. The treatments comprise two levels of STCR based fertilizers viz., 75 and 100% NPK with four types of organic manures viz., FYM, vermicompost, biochar and biochar composite. The treatments details are T₁ - Control (Recommended dose of fertilizer 200:100:100 kg of NPK ha⁻¹), T₂, T₄, T₆, T₈, T₁₀ consist 100% STCR based NPK with FYM 25 t ha⁻¹, Biochar 5 t ha⁻¹, Vermicompost 5 t ha⁻¹, Biochar composite 2.5 t ha⁻¹ and Biochar composite 5 t ha⁻¹ respectively. T₃, T₅, T₇, T₉, and T₁₁ consist 75% STCR based NPK with FYM 25 t ha⁻¹, Biochar 5 t ha⁻¹, Vermicompost 5 t ha⁻¹, Biochar composite 2.5 t ha⁻¹ and Biochar composite 5 t ha⁻¹ respectively.

The recommended NPK dose of fertilizer (200:100:100 kg of NPK ha⁻¹) for bhendi was applied in the form of urea, DAP and MOP at the rate of 349.7:217.4:166.7 Kg ha⁻¹. A full dose of phosphorous, potassium and half dose of nitrogen was applied as the basal and the remaining half dose of nitrogen at 30 DAS. Soil properties were analyzed at the critical stages of flowering and fruiting (40 and 70 DAS). Plant height was measured on 30, 60, 90 DAS and fruit length (cm), girth (cm), weight (g), yield (t ha⁻¹) and dry matter production (t ha⁻¹) were computed at harvest stage. The statistical analysis was carried out by AGRES software at 5% level of significance.

RESULTS AND DISCUSSION

Properties of *Prosopis* biochar

Prosopis is extensively grown in many parts of Tamil Nadu and it is available in large quantities, particularly in dry tracts and wastelands. The data obtained from the *Prosopis* biochar is presented in Table 1. pH and EC of *Prosopis* biochar and biochar composite was 9.4, 0.21 dS m⁻¹ and 8.50, 0.38 dS m⁻¹ respectively. The total carbon content and cation exchange capacity of the biochar was 839.8 g kg⁻¹ and 21.3 c mol (p+) kg⁻¹ and biochar composite have 651.93 g kg⁻¹ and 19.7 c mol (p+) kg⁻¹. With respect to total nutrient content, *Prosopis* biochar and biochar composite had a high amount of carbon and a low amount of total nitrogen (3.5 and 4.2 g kg⁻¹). *Prosopis* biochar and biochar composite had a low amount of total phosphorus (1.02 and 1.2 g kg⁻¹) and total potassium (4.3 and 4.1 g kg⁻¹) and also contained exchangeable cations like calcium (12.2 and 15.3 g kg⁻¹) and magnesium (0.47 and 0.92 g kg⁻¹).

Table 1. Characterization of biochar and biochar composite

Sl. No.	Characters	<i>Prosopis</i> Biochar	Biochar composite
1.	Moisture (%)	1.52	2.13
2.	Ash (w w ⁻¹)	1.40	1.76
3.	pH (1:10 solid water suspension)	9.40	8.50
4.	EC (dS m ⁻¹) (1:10 soil water extract)	0.21	0.38
5.	Cation exchange capacity (c mol (p ⁺) kg ⁻¹)	21.3	19.7
6.	Total carbon (g kg ⁻¹)	839.80	651.93
7.	Total Nitrogen (g kg ⁻¹)	3.5	4.2
8.	Total Phosphorus (g kg ⁻¹)	1.02	1.2
9.	Total Potassium (g kg ⁻¹)	4.3	4.1
10.	Calcium (g kg ⁻¹)	12.2	15.3
11.	Magnesium (g kg ⁻¹)	0.47	0.92

Table 2. Characteristics of experimental soil

Sl. No	Soil parameter	Soil characteristics
1	pH	7.95
2	EC (dS m ⁻¹)	0.44
3	Texture	Clay loam
4	Bulk density (Mg m ⁻³)	1.25
5	Particle density (Mg m ⁻³)	2.22
6	Pore space (%)	44.00
7	Organic carbon (g kg ⁻¹)	2.40
8	Available nitrogen (kg ha ⁻¹)	252.00
9	Available phosphorous (kg ha ⁻¹)	55.00
10	Available potassium (kg ha ⁻¹)	353.00
11	DTPA extractable Zn (mg kg ⁻¹)	0.98
12	DTPA extractable Fe (mg kg ⁻¹)	5.88
13	DTPA extractable Cu (mg kg ⁻¹)	1.8
14	DTPA extractable Mn (mg kg ⁻¹)	4.19
15	Soil series	Somayyanur

Effect of biochar composite along with STCR based fertilizers on soil properties

Soil pH and EC

Application of biochar composite at 5 t ha⁻¹ along with 75 % STCR based NPK (T₁₁) significantly influenced the soil pH. The slight increase in average soil pH (0.4) over the initial values was primarily due to calcium, magnesium salts of chloride and carbonate present in biochar. Similar studies by Whitman *et al.* (2016) in corn (*Zea mays*) using pyrogenic organic matter revealed an increase in soil pH. The application of biochar composite at 2.5 t ha⁻¹ along with 100 % STCR

NPK (T₈) was on par with the application of biochar composite at 5 t ha⁻¹ along with 100 % STCR NPK (T₁₀) in influencing the soil pH. The increase in average soil pH due to these treatments was mainly attributed to biochar's alkaline nature that increased the soil pH by 0.4 to 1.2 pH units. Similar findings were reported by Pandian *et al.* (2016) in groundnut while applying *prosopis* biochar at the rate of 5 t ha⁻¹ in sandy loam soil and Kannan *et al.* (2021) reported in *Vigna mungo* with the application of biochar and phosphobacteria that increased soil pH than biochar alone.

Application of biochar composite at 5 t ha⁻¹ along with STCR based NPK significantly influenced the soil EC.

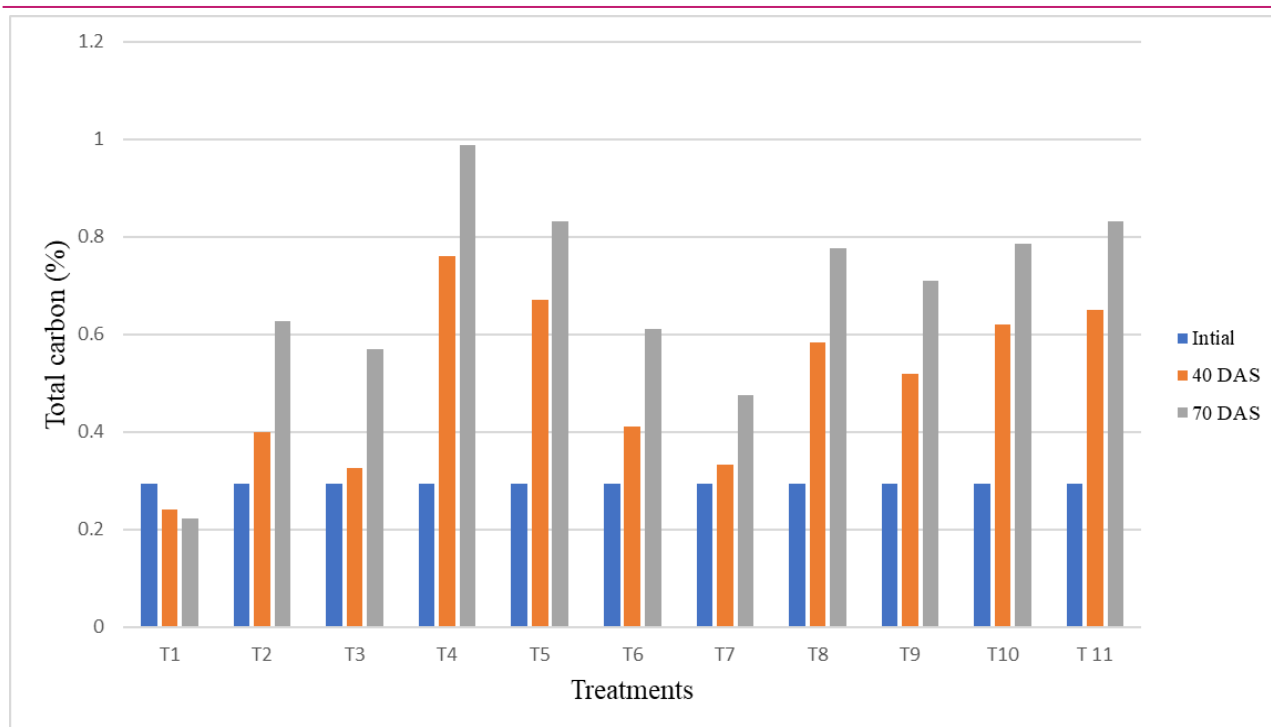


Fig. 1. Effect of biochar composite on total carbon content (%) in soil

The slight increase in soil EC in biochar and biochar composite treatments over their initial values is mainly attributed to the addition of soluble salts through biochar, leading to an increase in electrolyte concentration. Nigussie *et al.* (2012) reported that applying maize stalk biochar at the rate of 10 t ha⁻¹ increases the EC and pH in soils grown with lettuce crops.

Available nitrogen

Organic sources and inorganic fertilizer treatments significantly influenced soil available nitrogen content. The available nitrogen in the soil at flowering stage ranged from 252 kg ha⁻¹ in control to 295 kg ha⁻¹ in plots applied with biochar composite at 5 t ha⁻¹ along with 75% STCR (Table 3). Similarly, the same treatment recorded soil available nitrogen content of 243.8 kg ha⁻¹ at the fruiting stage of bhendi. Thus, it was observed that soil application of biochar composite at 5 t ha⁻¹ along with 75% STCR based NPK resulted in 17 and 16 % increase in available nitrogen over the control plots (252 kg ha⁻¹ and 209 kg ha⁻¹) during flowering and fruiting stages respectively. This treatment was significantly on par with the application of biochar composite at 2.5 t ha⁻¹ with 100% STCR based NPK.

The increase in available soil nitrogen in biochar composite at 5 t ha⁻¹ along with 75% STCR based NPK was mainly due to higher nutrient retention capacity and reduced nutrient leaching of the soils treated with biochar composite. Further, the efficient adsorption of ammonia (NH₃) at the planar surface of biochar might have reduced the volatilization loss, thus increasing the

available N status in the soils applied with 5 t ha⁻¹ of biochar composite along with STCR NPK. Tsutomu *et al.* (2004) reported bamboo charcoal carbonized at 500 °C having greater number of acidic functional groups, which lead to higher NH₃ removal efficiency. Similar results were reported by Adekiya *et al.* (2020) in ginger with combined application of biochar and NPK fertilizers. Vaccari *et al.* (2015) also reported that wheat bran biochar increases soil available NH₄⁺ in tomatoes. Singh *et al.* (2018) reported that application of biochar at increasing rates (10, 20 and 40 t ha⁻¹) increased soil available N compared to the unamended control by 17.4%, 23.2% and 27% in wheat.

Available phosphorus

Application of organic sources viz., FYM, vermicompost, biochar and biochar composite significantly influenced the available P compared to unmanured control. Among the treatments, biochar composite at 5 t ha⁻¹ with 75 % STCR based NPK (113.2: 17.04: 97.12 NPK Kg ha⁻¹) recorded the highest soil available P of 22.4 and 19.3 kg ha⁻¹ at flowering and fruiting stages, respectively. This treatment was on par with biochar application at 5 t ha⁻¹ with 100% STCR based NPK. The lowest values of 16.23 and 11.3 kg ha⁻¹ soil available phosphorous were observed at flowering and fruiting stages, respectively, in control plots that were applied with the recommended dose of fertilizer alone.

A significantly higher amount of soil available phosphorous in biochar composite applied plots might be due to its influence on cations (Ca, Mg, Al, Fe) that interacts

Table 3. Effect of biochar composite along with STCR based NPK on soil properties

Treatments	pH	EC	Available N (Kg ha ⁻¹)			Available P (Kg ha ⁻¹)			Available K (Kg ha ⁻¹)			Total carbon (%)		
			Flower- ing	Fruiting	Flowering	Fruiting	Flowering	Fruiting	Flowering	Fruiting	Flowering	Fruiting	Flowering	Fruiting
T ₁ Control (Recommended Dose of Fertilizer*)	8.08	0.31	252.20	209.40	16.23	11.30	262.00	247.30	0.240	0.223				
T ₂ 100% NPK STCR + FYM 25 t ha ⁻¹	8.15	0.42	265.30	225.10	19.10	16.00	289.00	272.00	0.400	0.627				
T ₃ 75 % NPK STCR + FYM 25 t ha ⁻¹	8.17	0.43	253.47	212.80	17.00	12.80	273.00	256.00	0.327	0.570				
T ₄ 100% NPK STCR + Biochar 5 t ha ⁻¹	8.24	0.41	282.73	232.80	22.10	18.90	351.00	334.00	0.760	0.989				
T ₅ 75% NPK STCR + Biochar 5 t ha ⁻¹	8.22	0.48	259.70	220.60	18.50	14.80	286.00	268.00	0.670	0.831				
T ₆ 100% NPK STCR + Vermicompost 5 t ha ⁻¹	8.20	0.31	280.40	230.10	19.80	16.70	316.00	298.00	0.411	0.611				
T ₇ 75% NPK STCR + Vermicompost 5 t ha ⁻¹	8.17	0.36	254.60	217.70	17.70	14.23	267.00	252.00	0.334	0.475				
T ₈ 100% NPK STCR + Biochar composite 2.5 t ha ⁻¹	8.22	0.27	292.87	240.40	20.40	17.27	330.00	304.00	0.584	0.776				
T ₉ 75% NPK STCR + Biochar composite 2.5 t ha ⁻¹	8.22	0.37	275.17	226.30	19.70	16.50	305.00	286.00	0.520	0.710				
T ₁₀ 100% NPK STCR + Biochar composite 5 t ha ⁻¹	8.29	0.35	289.63	239.90	21.00	18.20	339.40	317.40	0.620	0.787				
T ₁₁ 75% NPK STCR + Biochar composite 5 t ha ⁻¹	8.35	0.48	295.43	243.80	22.40	19.30	344.70	323.70	0.650	0.832				
SED	0.06	0.034	4.06	4.63	0.37	0.33	4.53	6.94	0.011	0.012				
CD (P=0.05)	0.126	0.071	8.48	9.66	0.77	0.69	9.45	14.47	0.023	0.024				

* Recommended Dose of Fertilizer – 200:100:100 kg of NPK ha⁻¹

Table 4. Effect of biochar composite along with STCR based NPK on growth and yield parameters of bhendi

Treatments	Plant height (cm)			Fruit length (cm)	Fruit girth (cm)	Fruit weight (g)	Dry matter production (t ha ⁻¹)	Yield (t ha ⁻¹)
	30 DAS	60 DAS	90 DAS					
T ₁ Control (Recommended Dose of Fertilizer)	37.40	60.32	76.93	11.61	4.90	13.85	9.593	18.233
T ₂ 100% NPK STCR + FYM 25 t ha ⁻¹	42.80	61.88	80.40	12.44	5.60	16.18	10.358	21.133
T ₃ 75 % NPK STCR + FYM 25 t ha ⁻¹	37.60	60.64	77.20	12.05	4.93	14.17	9.782	19.467
T ₄ 100% NPK STCR + Biochar 5 t ha ⁻¹	45.50	67.82	86.83	13.06	5.93	17.50	10.861	22.500
T ₅ 75% NPK STCR + Biochar 5 t ha ⁻¹	38.50	61.74	80.03	12.32	5.30	15.65	9.870	20.567
T ₆ 100% NPK STCR + Vermicompost 5 t ha ⁻¹	49.40	66.32	83.80	12.94	5.86	17.43	10.829	22.433
T ₇ 75% NPK STCR + Vermicompost 5 t ha ⁻¹	40.50	61.23	77.60	12.17	5.03	14.29	9.825	20.133
T ₈ 100% NPK STCR + Biochar composite 2.5 t ha ⁻¹	47.60	77.24	94.17	14.06	6.23	18.73	11.260	24.010
T ₉ 75% NPK STCR + Biochar composite 2.5 t ha ⁻¹	43.60	65.20	82.17	12.91	5.66	17.09	10.641	22.133
T ₁₀ 100% NPK STCR + Biochar composite 5 t ha ⁻¹	46.50	76.20	93.40	13.86	6.20	18.7	11.023	23.770
T ₁₁ 75% NPK STCR + Biochar composite 5 t ha ⁻¹	48.30	79.72	98.00	15.23	6.93	21.56	11.900	25.200
SED	1.08	1.24	1.88	0.27	0.092	0.38	0.15	0.51
CD	2.25	2.59	3.93	0.56	0.19	0.81	0.31	1.07

with phosphorous. Further, biochar's adsorption and desorption ability was found to influence the soil available P as already suggested by Kannan *et al.* (2021) in *Vigna mungo* with the combined application of red gram stalk biochar and phosphobacteria. Pandian *et al.* (2016) reported increased soil available P with the application of maize stalk biochar. Bornemann *et al.* (2007) reported that char produce from pyrolysis temperature of 850 °C had high surface area and sorption capacity. Application of biochar along with phosphorous protects P from the precipitation in soil, thus enhancing its availability compared to control plots. The higher carbon content of biochar (83.9 %) might have increased the microbial activity facilitating the insoluble form of P into plant-available soluble form of P. El-Naggar *et al.* (2019) also reported that the application of wood biochar with poultry manure composite increased the P availability in soil.

Available potassium

The highest amount of 351 kg ha⁻¹ and 334 kg ha⁻¹ soil available potassium was observed in soils that received biochar at 5 t ha⁻¹ along with 100 % STCR based NPK at flowering and fruiting stages, respectively. This treatment was followed by that which received biochar composite at 5 t ha⁻¹ with 75 % STCR based NPK. The lowest amount of 262 kg ha⁻¹ and 247.3 kg ha⁻¹ of soil available potassium were observed in control plots. The increase in available K due to biochar application is contributed by the relatively higher content of potassium present in it as revealed by the basic characterization of the organic manures used in this study. Similar findings have also been observed by Pandian *et al.* (2016), who reported that applying red gram and cotton stalk biochar increases soil available potassium in groundnut.

Total carbon

The initial total carbon content of the soil was 0.294 percent. Application of biochar at the rate of 5 t ha⁻¹ along with 100 % STCR based NPK significantly increased the total carbon content to 0.760 % and 0.989 % over the initial value at flowering and fruiting stages of bhendi crop respectively (Figure 1). The increase in total carbon content in soil mainly attributed by addition of carbon rich *prosopis* biochar into soil, which has total carbon content of 83.98 %. The lowest total carbon was observed in control plots. The influence of application of vermicompost 5 t ha⁻¹ (12.6%) and application of FYM 25 t ha⁻¹ (16.6%) were on par with each other in influencing the total carbon status of soil. Shenbagavalli and Mahimairaja (2012) reported that *prosopis* biochar had high carbon content of 940 g kg⁻¹. Similar findings were reported by Kannan *et al.* (2021) in *Vigna mungo* with the application of red gram stalk and Australian

acacia biochar.

Effect of biochar composite on growth and yield parameters of bhendi

Plant height

A significant variation in plant height was recorded with application of different levels of biochar composite and STCR based NPK nutrients. The plant height was maximum (98 cm) in biochar composite at 5 t ha⁻¹ along with 75 % STCR based NPK while it was minimum (76.93 cm) in control (Table 4). The positive effects of carbon content of the biochar based organic sources might have improved the soil environment thus enhancing the soil available nitrogen, contributing to its better vegetative growth than other treatments. Similar findings were observed by Dos santos Farias *et al.* (2020) reported that the application of sewage sludge biochar and sewage sludge biochar and raw sewage sludge increases the plant height of okra plants 60% and 55.4 %, respectively, in comparison to control treatment. Gokila (2017) reported an increase in maize plant height with the combined application of *prosopis* biochar, azophos and 100 % of the recommended dose of fertilizer. Hossain *et al.* (2019) reported that the application of fertilized farmyard manure biochar and fertilized domestic organic waste biochar increased the plant height of data shak (*Amaranthus lividus*) vegetables.

Yield parameters, yield and dry matter production

Application of biochar composite at 5 t ha⁻¹ along with 75 % STCR based NPK recorded maximum fruit length (15.23), girth (6.93) and weight (21.56 g). This was followed by the application of biochar composite at 2.5 t ha⁻¹ along with 100 % STCR based NPK which was also on par with application of biochar composite at 5 t ha⁻¹ along with 100 % STCR based NPK. Significant changes brought by addition of biochar composite and biochar on soil pH, cation exchange capacity and soil organic matter might have helped nutrient retention in soil that increased the nutrient replenishment and nutrient availability, thus facilitating better nutrient uptake resulting in higher yields. Similar findings were reported by Kannan *et al.* (2013) and Oldfield *et al.* (2018), who have attributed the yield increase in field crops of rice (800%), wheat (250%) and groundnut (55%) applied with biochar by improving the complex of physical, chemical and biological properties of the acidic soil as influenced by biochar application. Application of biochar composite at 5 t ha⁻¹ along with 75 % STCR based NPK recorded the highest yield of 25.2 t ha⁻¹ and maximum dry matter production of 11.9 t ha⁻¹. This was 38 % and 24 % respective increase over control, respectively. The nutrients supplied by NPK fertilizer in this

experiment might have been prevented from leaching in biochar and biochar composite treated plots, thus increasing the retention of these nutrients in the soil and by the crop contributing to higher yield. Similarly, Di et al. (2019) reported combined application of wheat straw biochar with vermicompost increased the rice yield compared to that vermicompost without biochar. Adekiya et al. (2020) reported increased rhizome yield of ginger with the application of hardwood biochar plus NPK fertilizer.

Conclusion

The results of the study on evaluation of biochar composite for improving soil properties and yield of bhendi (*A. esculentus*) proved that combined application of 75 % STCR with biochar composite at 5 t ha⁻¹ positively influenced the physical properties (water retention and infiltration) and chemical properties (CEC, pH, total carbon content) of soil thus contributing to better availability of nutrients. It also enhanced the nutrient uptake, yield (25.2 t ha⁻¹) and biomass (11.9 t ha⁻¹) of the bhendi crop. The findings also established the fact that 25 % STCR based NPK can be reduced with the application of 5 t ha⁻¹ of biochar composite, indicating the nutrient use efficiency and nutrient retention capacity potential of biochar and biochar composite.

Conflict of interest

The authors declare that they have no conflict of interest.

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