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Biochar for Enhancing Yield, Nutrient Uptake, and Soil Fertility in Okra

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Abstract

The beneficial role of biochar in improving soil fertility is well known, but the optimal application rate in sandy loam soils remains unclear. To address this gap, a field experiment was conducted in 2023 on the coastal sandy loam soils of Kayamkulam, Kerala, to assess the impact of different biochar rates on okra yield, nutrient uptake, and soil fertility. The study followed a randomized block design with nine treatments: various combinations of biochar (5 and 10 t ha^{-1}), farmyard manure (5 and 20 t ha^{-1}), and two nutrient levels (75% and 100% RDF). Results revealed that the application of biochar at 10 t ha^{-1} along with the recommended nutrient dose (110:35:70 kg N:P_2O_5:K_2O ha^{-1}) significantly improved okra yield and nutrient uptake while enhancing soil fertility. The findings highlight the potential of biochar as a soil conditioner and underscore the importance of application rate for achieving optimal benefits.

Keywords: biochar, okra, nutrient uptake, soil fertility, coastal sandy loam, Kerala.

1. Introduction

In India, the agricultural waste generated by crops is significantly higher than in many other countries. Due to the lack of suitable technologies for effective disposal, farmers often resort to burning the crop residues as a quick and convenient method to clear fields. According to Singh and Kaskaoutis (2014), about 43% of the total crop stubbles produced in India is burnt in-situ, contributing substantially to air pollution. One promising solution to mitigate the environmental impact of crop residue burning is the conversion of crop residues into biochar, a carbon rich material produced through pyrolysis. Punnoose and Anitha (2015) has reported that biomass possesses several beneficial physical properties including low bulk density, high porosity, and higher water holding capacity. When applied to soil, these properties make biochar, an effective soil conditioner, enhancing both water and nutrient retention in soil and improves the crop yield. In Kerala, tender coconut husk is a prominent form of agricultural waste which requires efficient and ecofriendly disposal methods. Although, a portion of this agricultural waste is currently utilized through composting or as mulch in coconut gardens, these practices are insufficient relative to the large volume of waste produced. The dried tender coconut husk holds significant potential for conversion into biochar, which can then be recycled back into agricultural use to boost soil productivity. The Onattukara tract spread over three districts of Kerala (Alappuzha, Kollam and Pathanamthitta) presents a unique challenge due to its coarse textured, sandy loam soils with inherently low nutrient status. This type of soil is prone to nutrient leaching, especially during rainfall, rendering the applied fertilizers as less effective. Given biochar's ability to improve soil moisture retention and reduce nutrient leaching, it represents a promising amendment for such type of soils. Therefore, a study was conducted to evaluate the potential of tender coconut husk biochar as a soil conditioner for okra cultivation in the sandy loam soils of Onattukara region.

2. Materials and methods

A field experiment was conducted during the summer of 2023 in the wetlands of the Instructional Farm attached to Onattukara Regional Agricultural Research Station, Kayamkulam, Kerala. The research station is situated at 9.177° North latitude and 76.517° East longitude and at an altitude of 3.05 m above mean sea level. The treatments were laid out in randomized block design comprising of eight treatment combinations of biochar along with two levels of recommended dose of nutrients for okra along with a control and were replicated thrice. The treatments were t1 (biochar @ 5 t ha^{-1} + 100% RDF)[1], t2 (biochar @ 10 t ha^{-1} + 100% RDF), t3 (biochar @ 5 t ha^{-1} + 5 t ha^{-1} FYM + 100% RDF)[2], t4 (biochar @ 10 t ha^{-1} + 5 t ha^{-1} FYM + 100% RDF), t5 (biochar @ 5 t ha^{-1} + 75% RDF), t6 (biochar @ 10 t ha^{-1} + 75% RDF), t7 (biochar @ 5 t ha^{-1} + 5 t ha^{-1} FYM + 75% RDF), t8 (biochar @ 10 t ha^{-1} + 5 t ha^{-1} FYM + 75% RDF), and t9 (KAU POP (2016)-20 t ha^{-1} FYM + 100% RDF).

Prior to sowing, the experimental area was cleared of stubbles and clods were broken thoroughly. Dolomite was applied uniformly at the rate of 1 t ha^{-1} and was incorporated in soil during primary tillage. The field was laid out as per the treatment design. After the layout, biochar and farmyard manure, along with half N, full P and full K of chemical fertilizers were

[1] RDF=Recommended Dose of Fertilizer
[2] FYM=Farm Yard Manure

applied in soil as per the treatments just before sowing. The remaining N was given in soil at one month after sowing along with intercultural operations and earthing up. The seeds of okra var. Arka Anamika were sown in lines in the main field at a spacing of 60 cm × 30 cm. The crop was sown during the last week of January 2023. After sowing, uniform population was maintained by thinning and gap filling. Five random plants from each net plot were selected and tagged as observational plants for recording observations.

The number of days taken for the first flower to open was noted and the mean was worked out. To find the number of fruits per plant, the fruits obtained from different harvests from each of the five observational plants were recorded separately and the average was worked out. The length of the fruits, from the tip of the fruit to the stalk end, was measured from the observational plants and the average was calculated and expressed in cm. The weight of the fruits harvested from each of the observational plants was recorded after each harvest. After the final harvest, the total weight of fruits obtained from the observational plants at different harvests were worked out, averaged and expressed in kilograms for fruit yield per plant. The weight of fruits from each plot excluding the border plants was recorded after each harvest and summed at the end of the cropping season to compute the yield in terms of kg per plot and was converted into t ha^{-1}.

The harvest index was calculated using the following formula suggested by Donald and Hamblin (1976). It was calculated by dividing the economic yield with biological yield of the plant. Sample plants collected from each plot were chopped into small pieces and were sun dried. After the initial drying, the samples were dried in oven to attain constant weight. The samples were then ground to pass through a 0.5 mm mesh and the required quantity of samples were digested and used for nutrient analysis following standard procedures. The nutrient uptake was calculated and expressed in kg ha^{-1} according to Equation 1.

$$\text{Nutrient uptake (kg ha}^{-1}) = \frac{\text{Nutrient content (\%)} \times \text{Dry matter production (kg ha}^{-1})}{100} \quad (1)$$

The composite soil samples from the field before the experiment and from each plot after the experiment were collected, air dried, powdered and passed through a 2 mm sieve and analysed for physico-chemical properties of the soil (Table 1). The soil samples passed through 0.2 mm sieve were used for organic carbon estimation. Values represented in Table 1 are initial soil values.

Sl. No.	Characters	Values	Methods	Reference
1	Water holding capacity (%)	10.47	Core sampling	Black (1965)
2	Bulk density (Mg m^{-3})	1.61	Undisturbed core sample	
3	Soil reaction (pH)	5.38	pH meter (1:2.5 soil water ratio)	Jackson (1958)
4	EC (dS m^{-1})	0.01	Conductivity meter (1:2.5 soil water ratio)	Jackson (1958)

Sl. No.	Characters	Values	Methods	Reference
5	CEC (cmol(+) kg^{-1})	2.28	Ammonium saturation with neutral normal ammonium acetate and distillation	Jackson (1973)
6	Organic carbon (%)	0.53	Walkley and Black rapid titration method	Walkley and Black (1934)
7	Available N (kg ha^{-1})	200.7	Alkaline permanganate method	Subbiah and Asija (1956)
8	Available P (kg ha^{-1})	90.27	Bray No. 1 extraction and spectrophotometric estimation	Jackson (1973)
9	Available K (kg ha^{-1})	177.18	NH OAc extraction and flame photometry	Jackson (1958)
10	Exchangeable Ca (mg ha^{-1})	169.26	NH OAc extraction and AAS estimation	Hesse (1971)
	Exchangeable Mg (mg ha^{-1})	53.6		
11	Available S (mg ha^{-1})	2.71	CaCl extraction and spectrophotometric estimation	Chesnin and Yien (1950)
12	Available Fe (mg kg^{-1})	14.74	DTPA extraction and AAS estimation	Lindsay and Norvell (1978)
	Available Mn (mg kg^{-1})	3.44		
	Available Cu (mg kg^{-1})	1.31		
	Available Zn (mg kg^{-1})	3.44		
13	Available B (mg kg^{-1})	0.59	Hot water extraction and azomethane-H spectrophotometric estimation	Hesse (1971)

Table 1: Standard analytical procedures used for the soil analysis

3. Results

3.1. Yield and plant performance

The application of biochar significantly influenced certain yield traits of okra. Days to flowering ranged between 35 and 37 days after sowing (DAS) across all treatments, but the differences were not statistically significant. Similarly, the number of fruits per plant and fruit length did not differ significantly among treatments. However, fruit yield per plant was significantly affected by biochar application (Table 2). Treatment t4 resulted in the highest fruit yield per plant (544.93 g) and was statistically at par with t3 (537.74 g), while the lowest was recorded in t9 (380.24 g). Yield per hectare followed a similar trend, with t4 yielding 15.71 t ha^{-1} and was found to be on par with t3 (14.07 t ha^{-1}), and the lowest yield observed in t9 (7.65 t ha^{-1}). The harvest index was also positively influenced, with t3 registering the highest value (0.81), which was statistically similar to t4 (0.81), t2 (0.79), t1 (0.79), and t8 (0.77).

3.2. Nutrient uptake

The nutrient uptake of okra plants varied across treatments. Nitrogen uptake was significantly higher in t4 (101.35 kg ha^{-1}), which was on par with t3, t2, t6, and t5. The lowest N uptake (74.78 kg ha^{-1}) was recorded in t9. Phosphorus uptake was highest in t7 (24.76 kg ha^{-1}), statistically similar to t8, t6, t5, and t3, while t2 had the lowest (14.90 kg ha^{-1}). Potassium uptake was not significantly affected by any treatment. For calcium, t6 showed the highest uptake (64.94 kg ha^{-1}), comparable to t3, t7, and t4. Magnesium uptake was also significantly influenced, with t4 showing the highest uptake (20.47 kg ha^{-1}), on par with t3, t6, and t8. Sulphur uptake did not differ significantly across treatments. Copper uptake was highest in t1 (1.82 kg ha^{-1}), followed closely by t3 (1.73 kg ha^{-1}), while the lowest was in t6 (0.89 kg ha^{-1}). Zinc and boron uptakes were not significantly influenced by treatments. Iron uptake was significantly higher in t6 (0.96 kg ha^{-1}), which was at par with t1 and t3. Manganese uptake was highest in t8 (1.69 kg ha^{-1}), statistically similar to t7, t4, and t2.

3.3. Soil properties

Post-harvest soil analysis revealed that biochar application significantly influenced several soil physico-chemical parameters. Water holding capacity was significantly higher in t4 (33.87%), followed by t8, t3, t2, and t7. Bulk density was lowest in t8 (1.21 Mg m^{-3}), while t9 recorded the highest (1.30 Mg m^{-3}). No significant differences were found in soil pH, electrical conductivity (EC), or cation exchange capacity (CEC). Organic carbon content increased significantly with biochar application, highest in t4 (1.29%), and statistically comparable to t8, t3, t2, t7, t1, and t6. Available nitrogen content also improved, with t4 (209.07 kg ha^{-1}) showing significantly higher values, followed by t3, t8, and t7. However, the availability of phosphorus, potassium, calcium, magnesium, sulphur, copper, zinc, iron, boron, and manganese in the soil was not significantly affected by the treatments.

Treatment	Days to Flowering	No. of Fruits/Plant	Fruit Length (cm)	Fruit Yield/Plant (g)	Fruit Yield (t ha^{-1})	Harvest Index
t1	38.67	18.00	15.90	480.30	10.44	0.79
t2	38.67	18.12	16.07	487.23	12.25	0.79
t3	38.44	19.90	16.28	537.74	14.07	0.81
t4	38.67	20.23	16.34	544.93	15.71	0.81
t5	38.67	16.11	15.55	392.85	11.26	0.74
t6	38.78	16.79	15.74	415.59	11.89	0.76
t7	38.89	17.45	15.81	457.61	12.19	0.77
t8	38.67	17.56	15.85	464.61	13.05	0.77
t9	38.67	16.11	15.40	380.24	7.65	0.75
SEm (±)	0.14	1.33	0.35	16.81	0.63	0.01
CD (0.05)	NS	NS	NS	50.385	1.890	0.037

Table 2: Effect of treatments on the yield attributes and yield of okra

Treatment	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
t1	87.85	17.07	51.93
t2	92.90	14.90	49.52
t3	95.93	19.60	53.88
t4	101.35	18.45	46.64
t5	91.93	19.98	46.68
t6	92.70	22.57	55.40
t7	88.15	24.76	46.47
t8	84.43	23.73	50.65
t9	74.78	17.87	45.96
SEm (±)	4.29	1.86	3.42
CD (0.05)	12.848	5.561	NS

Table 3: Effect of treatments on nutrient uptake of okra (N, P, and K)

Treatment	Ca	Mg	S	Cu	Zn	Fe	B	Mn
t1	53.28	18.27	3.00	1.82	1.86	0.88	0.30	1.36
t2	52.78	18.00	3.10	1.70	1.83	0.47	0.34	1.46
t3	59.72	19.84	3.06	1.73	1.85	0.82	0.32	1.40
t4	58.61	20.47	3.14	1.19	1.92	0.44	0.34	1.67
t5	54.39	16.54	3.03	0.67	1.92	0.67	0.30	1.42
t6	64.94	19.61	3.05	0.89	1.85	0.96	0.33	1.61
t7	59.38	18.66	2.98	1.09	2.04	0.74	0.31	1.68
t8	56.25	19.60	3.07	1.34	2.01	0.78	0.33	1.69

Treatment	Ca	Mg	S	Cu	Zn	Fe	B	Mn
t9	41.10	18.68	2.98	1.68	1.93	0.78	0.31	1.39
SEm (±)	2.21	0.35	0.05	0.04	0.18	0.05	0.02	0.08
CD (0.05)	6.610	1.061	NS	0.111	NS	0.151	NS	0.251

Table 4: Effect of treatments on uptake of nutrients by okra (all values in kg ha^{-1})

Treatment	WHC (%)	Bulk Density (Mg m^{-3})	pH	EC (dS m^{-1})	CEC (cmol(+) kg^{-1})	Organic Carbon (%)
t1	30.78	1.26	5.48	0.03	3.11	1.19
t2	32.65	1.22	5.78	0.03	3.12	1.23
t3	32.73	1.23	5.59	0.02	3.06	1.25
t4	33.87	1.22	5.87	0.03	3.11	1.29
t5	29.45	1.24	5.66	0.02	3.08	1.10
t6	30.91	1.22	5.76	0.09	3.09	1.17
t7	32.61	1.22	5.67	0.04	3.11	1.23
t8	33.02	1.21	5.84	0.02	3.07	1.26
t9	27.52	1.30	5.31	0.03	3.05	0.96
SEm (±)	0.57	0.00	0.11	0.03	0.04	0.05
CD (0.05)	1.695	0.008	NS	NS	NS	0.134

Table 5: Effect of treatments on soil parameters after harvest of okra

Treatment	Available N	Available P	Available K
t1	188.16	76.91	161.43
t2	188.16	79.63	152.13
t3	196.52	76.36	146.46
t4	209.07	94.90	172.70
t5	163.07	80.72	189.47
t6	163.07	82.73	159.64
t7	196.52	88.00	172.03
t8	196.52	75.09	173.26
t9	183.98	73.63	149.74
SEm (±)	6.97	7.08	10.63
CD (0.05)	20.890	NS	NS

Table 6: Effect of treatments on primary nutrient status of soil after the experiment (all values in kg ha^{-1})

Treatment	Ex.[3] Ca	Ex. Mg	Available S	Available Cu	Available Zn	Available Fe	Available B	Available Mn
t1	446.10	83.08	2.53	1.45	2.35	14.72	0.29	3.78
t2	437.03	87.28	3.19	1.43	2.62	15.42	0.29	3.81
t3	426.70	88.68	2.69	1.45	2.64	15.38	0.29	3.95
t4	403.75	88.19	2.84	1.42	2.40	15.38	0.29	3.74
t5	456.83	72.93	2.22	1.33	2.67	15.21	0.28	3.99
t6	398.10	80.63	2.86	1.34	2.42	15.53	0.27	3.95
t7	391.80	89.02	2.82	1.28	2.18	15.14	0.28	3.83
t8	407.92	89.90	3.06	1.40	2.14	14.82	0.28	3.45
t9	376.03	84.69	2.67	1.33	2.63	14.82	0.28	3.47
SEm (±)	21.62	4.94	0.19	0.05	0.18	0.46	0.01	0.16
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Table 7: Effect of treatments on secondary and micronutrient status of soil after the experiment (all values in mg kg^{-1})

4. Discussion

4.1. Yield attributes

The treatments did not influence the days taken to flower in okra. In general, regardless of the treatments, the okra plants started to flower between 35 DAS and 37 DAS. The number of fruits per plant and length of fruits were not influenced by biochar. However, the fruit yield per plant was significantly improved by the incorporation of biochar. The highest yield per plant was obtained from t4 (544.93 g) and was found to be on a par with the treatment t3 (537.74 g per plant). There was 35.60 per cent increase over t9. Higher fruit yield per plant was observed for the plants that received biochar and FYM along with 100 per cent recommended dose of fertilizers (RDF). The adsorbing property of biochar in sandy loam soil might have slowed down the release of nutrients from FYM and chemical fertilizers. As the amount of biochar was doubled, there was an increase in fresh weight of fruits. This is in accordance with the findings of Dainy (2015) who also reported a progressive increment in the yield characters in yard long bean as the levels of biochar was enhanced from 10 to 30 t ha^{-1} when applied along with the recommended dose of fertilizers. Similar reports of increased yield with the incorporation of biochar and RDF were also reported by Punnoose (2015) in amaranthus and Hashmi *et al.* (2019) in *Pisum sativum* L. In the case of fruit yield ha^{-1}, the application of tender coconut husk biochar had significantly improved the yield per hectare in okra. Higher fruit yield per hectare was observed for the treatment t4 (15.71 t) and was on par with t3 (14.07 t). The control plants (t9) could only produce 7.65 t ha^{-1}. Overall, there was a yield increase of 69 per cent in t4 compared to t9. The lower yield in t9 might be due to the leaching loss of nutrients. There was 44 mm rainfall during the growth period

[3] Ex. stands for Exchangeable

of okra at Onattukara which might have aggravated the leaching loss in the sandy loam soils of Onattukara. Nagula (2017) had also recommended the application of biochar (@ 10 kg ha^{-1}) along with RDN for higher yield in banana. The harvest index was also significantly influenced by the treatments. The treatment t3 recorded a higher harvest index of 0.81 and was found to be on a par with the treatments t4 (0.81), t2 (0.79), t1 (0.79) and t8 (0.77). Thus, biochar as a soil conditioner along with FYM and full recommended dose of fertilizers was effective for okra in the sandy loam soils of Onattukara.

4.2. Nutrient uptake

The N uptake in okra was significantly improved due to the treatments. Among the treatments, the highest N uptake was recorded by the treatment t4 (101.35 kg ha^{-1}) and was found to be on a par with t3 (95.93 kg ha^{-1}), t2 (92.90 kg ha^{-1}), t6 (92.70 kg ha^{-1}) and t5 (91.93 kg ha^{-1}). Lower N uptake was recorded in t9. There was an increase of 30.14 percent in the N uptake (t4) compared to control (t9). This might be due to the adsorbing capacity of biochar applied as soil conditioner. The higher CEC for biochar might have helped in retaining N in the sandy loam soils of Onattukara. The full RDN along with FYM (5 t ha^{-1}), combined with the adsorbing property of biochar might have contributed to a higher status of available N in soil and led to an increased uptake of N by okra. Dainy (2015) had earlier reported that the total N uptake in yard long bean was found to increase from 51.19 kg ha^{-1} to 105.50 kg ha^{-1} due to the application of biochar, PGPR and full recommended dose of nutrients. Jabin (2022) had also reported that total N uptake was higher in ginger when treated with paddy husk biochar (30 t ha^{-1}) along with full dose of fertilizers in sandy soils. Similarly, Nigussie *et al.* (2012) had also reported a higher N uptake in lettuces grown in soils conditioned with 10 t ha^{-1} biochar suggesting the prospects of biochar to raise fertilizer use efficiency in soils where N loss is high.

A significant difference was observed in P uptake among the treatments. Higher P uptake was observed for t7 (24.76 kg ha^{-1}) and was on a par with t8 (23.73 kg ha^{-1}), t6 (22.57 kg ha^{-1}), t5 (19.98 kg ha^{-1}) and t3 (19.60 kg ha^{-1}). This increase in P uptake might be due to the higher quantity of available P in soil which is evident from the soil samples collected after the harvest of okra (Table 6). In acidic soils, the solubility of P and its uptake by plants depends mainly on the formation of Al and Fe-phosphates in soil. When biochar is applied to acidic soil condition, it raises the soil pH. There is a reduction in the P binding to Fe and Al oxides, thus making P available in soil. Similar reports of improved P availability in acid soils due to supplementation of biochar was observed by Chintala *et al.* (2014) and Zhang *et al.* (2016). On the contrary, Dainy (2015) and Jabin (2022) had reported a higher P uptake in yard long bean and ginger, treated with biochar along with NPK as per KAU POP (2016). The uptake of K was not significantly influenced by the treatments.

Significant effect for Ca uptake was observed in okra (Table 4). The highest Ca uptake was recorded by the treatment t6 (64.94 kg ha^{-1}) and was noticed to be on a par with treatment t3 (59.72 kg ha^{-1}), t7 (59.38 kg ha^{-1}) and t4 (58.61 kg ha^{-1}). Lower Ca uptake was recorded by the treatment t9 (KAU POP). There was an overall increase of calcium uptake by 44.96% in t6 compared to the control t9. The application of biochar along with liming prior to planting okra was found to improve the availability of calcium in soil which might have led to an increased plant uptake. Earlier, Sombroek *et al.* (1993) had also reported increased calcium availability for plant growth after the application of biochar due to the higher surface area, negative surface charge and charge density. Moreover, calcium in biochar may exchange Al ions present on the soil organic matter and enhance the availability of calcium for plants thus, guiding it to an increased calcium uptake by the plants (Novak *et al.* 2009). Dainy (2015) had also reported higher Ca uptake in yard long bean due to the application of biochar. In sandy soils, Jabin (2022) also observed a higher calcium uptake in ginger.

The uptake of Mg was observed to be significant (Table 4). The treatment t4 resulted in higher Mg uptake (20.47 kg ha^{-1}) by okra and was noticed to be on a par with the treatment t3 (19.84 kg ha^{-1}), t6 (19.61 kg ha^{-1}) and t8 (19.60 kg ha^{-1}). The Mg in soil increases with increase in soil pH. There was an increment in soil pH from the initial value of 5.38 (Table 1) to 5.87 (Table 5) due to application of biochar in combination with the effect of liming. This might have improved the exchangeable magnesium in soil which has resulted in an increased magnesium uptake in okra. Jabin (2022) has also reported an increased magnesium uptake in ginger due to application of biochar. Tender coconut husk biochar had 0.13 percent magnesium (Vikram *et al.* 2024). This might have contributed to the higher magnesium content in t4. Dainy (2015) had also reported an increase in total Mg uptake in yard long bean when biochar (@ 20 t ha^{-1}) was applied with RDN. The uptake of sulphur was not significantly influenced by the treatments.

Copper uptake was found to be significant (Table 4) for the treatments. Higher copper uptake in okra was observed for the treatment t1 (1.82 kg ha^{-1}) and was found to be on a par with the treatment t3 (1.73 kg ha^{-1}). There was an increase in copper content in soil from 1.31 mg kg^{-1} (Table 1) to 1.45 mg kg^{-1} (Table 7) due to the application of biochar. This might have contributed to the increased uptake of copper in okra. Similar reports of increased copper uptake were noticed in yard long beans by Dainy (2015) and in rice by Salvacion and Pangga (2020) due to the application of biochar.

The uptake of zinc was not significantly influenced by the treatments. The uptake of iron in okra was found to be significant (Table 4). Higher iron uptake was observed for t6 (0.96 kg ha^{-1}) and was perceived to be on a par with treatment t1 (0.88 kg ha^{-1}) and t3 (0.82 kg ha^{-1}). The biochar produced from tender coconut husk contains 107.58 mg kg^{-1} of iron (Vikram *et al.* 2024), and hence its application as a soil conditioner had increased the soil iron content. The initial soil available iron was 14.74 mg kg^{-1} (Table 1) and was increased to 15.53 mg kg^{-1} (t6 – Table 7) due to the application of biochar. This might be the reason for the increased availability of iron in soil which might have contributed to the increased iron uptake in t6 treatment. Similar report of increased iron uptake in yard long bean was observed by Dainy (2015).

The uptake of boron was not significantly influenced by the treatments. The uptake of manganese was found to be significantly influenced by the treatments (Table 4). Among the treatments, the highest uptake of manganese was recorded by the treatment t8 (1.69 kg ha^{-1}) and was observed to be on a par with treatment t7 (1.68 kg ha^{-1}), t4 (1.67 kg ha^{-1}), t6 (1.61 kg ha^{-1}) and t2 (1.46 kg ha^{-1}). The application of biochar had slightly improved the soil available manganese. This might have improved the plant uptake of manganese in okra. Earlier, Dainy (2015) had also reported the increase in total uptake of manganese from 559.93 to 1140.50 g ha^{-1} due to application of biochar in yard long bean.

5. Soil attributes

The soil water holding capacity after cultivation of okra was significantly modified due to the treatments. The initial water holding capacity of the soil from the experimental area (Table 1) was 10.47%. The treatment t4 recorded a significantly higher WHC (33.87%) and was found on a par with t8 (33.02%), t3 (32.73%), t2 (32.65%) and t7 (32.61%). An increase of 20.68% in water holding capacity was observed in t4 (compared to control). An overall increase of 105.55% of WHC could be obtained due to application of biochar in the sandy loam soils of Onattukara. The initial analysis of tender coconut husk biochar had revealed that it had a water holding capacity of 232.34%. This biochar when applied to soil reduces the bulk density of soil and is the reason for the higher water holding capacity of the soil. There was 57.92% increase in WHC with the application of biochar along with NPK as per POP recommendation (Dainy 2015). Wang *et al.* (2019) has also reported that biochar can temporarily increase the field capacity due to their higher pore volume in a coarse textured soil.

The bulk density of soil was found to be significantly reduced by the treatments. The initial bulk density of the soil from the experimental area was 1.61 Mg m^{-3}. In general, biochar had significantly reduced the soil's bulk density. KAU 2016 (t9) recorded the highest bulk density (1.30 Mg m^{-3}) in soil and the lowest was recorded for the treatment t8 (1.21 Mg m^{-3}). Overall, there was a reduction in bulk density by 28.37% compared to the initial value indicating the potential for increased water holding capacity. There are several reports of decreased bulk density with application of biochar (Laird *et al.* 2010; Jones *et al.* 2010; Chen *et al.* 2011; Mankasingh *et al.* 2011; Zhang *et al.* 2012). Dainy (2015) had also reported in yard long bean that the application of biochar had lowered the bulk density of soil. The pH, electrical conductivity and CEC in soil after the experiment was not significantly influenced by the treatments.

The organic carbon content of the soil after the experiment was significantly governed by the treatments. Higher organic carbon was noticed for t4 (1.29%) and was on par with t8 (1.26%), t3 (1.25%), t2 (1.23%), t7 (1.23%), t1 (1.19%) and t6 (1.17%). The control treatment (t9) recorded the lowest organic carbon content (0.96%). There was an overall increase of 29.33% in t4 compared to KAU (2016) due to the application of biochar. The initial organic carbon content in soil before the experiment was 0.53% (Table 1). Biochar produced from tender coconut husk had a total organic carbon content of 48.14% (Vikram *et al.* 2024), and application of this might have helped in the increased carbon content in biochar applied plants. In amaranthus, Punnoose and Anitha (2015) had also reported higher organic carbon content in biochar applied plants.

There were significant effects on available N in soil. Higher available N was observed for t4 (209.07 kg ha^{-1}) and was on a par with the treatments t3, t7 and t8 with 196.52 kg ha^{-1}. This might be due to the increased retention of nitrogen in soil due to the application of biochar. Punnoose (2015) had also reported an increased nutrient content in biochar applied soils. The control (t9) recorded an available N content of 183.98 kg ha^{-1}. There was 44 mm of rain during the crop period which might have leached out the available N in soil leading to a comparatively lesser available N in soil. The lowest available N was recorded for t5 and t6 with 163.07 kg ha^{-1}. The lower dose of fertilizer without the application of FYM might have led to the lowest available N in soil.

6. Conclusion

It could be concluded that the rate of biochar as a soil conditioner for okra in the sandy loam soils of Onattukara is standardized as 10 t ha^{-1}. The soil application of biochar at the rate of 10 t ha^{-1} along with 5 t ha^{-1} FYM and 100% RDF could be recommended for enhancing yield, nutrient uptake and soil fertility in okra.

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References

Black CA (1965). *Methods of Soil Analysis. Part I.* American Society of Agronomy, Madison, Wisconsin, USA.

Chen H, Du Z, Guo W, Zhang Q (2011). "Effects of biochar amendment on cropland soil bulk density, cation exchange capacity, and particulate organic matter content in the North China plain." *Journal of Applied Ecology*, **22**, 2930–2934.

Chesnin L, Yien C (1950). "Turbidimetric determination of available sulphates." *Soil Science Society of America Proceedings*, **15**, 149–151.

Chintala R, Mollinedo J, Schumacher T, Malo D, Julson J (2014). "Effect of biochar on chemical properties of acidic soil." *Archives of Agronomy and Soil Science*, **60**(3), 393–404.

Dainy M (2015). *Investigation on the efficacy of biochar from tender coconut husk for enhance crop production.* Ph.D. thesis, Kerala Agricultural University, Thrissur. Ph.D. (Ag) thesis, 208p.

Hashmi S, Younis U, Danish S, Munir T (2019). "Pongamia pinnata L. leaves biochar increased growth and pigment syntheses in Pisum sativum L. exposed to nutritional stress." *Agriculture*, **9**(7), 1–13.

Hesse PR (1971). *A Textbook of Soil Chemical Analysis.* William Clowes and Sons, London.

Jabin N (2022). *Biochar for carbon sequestration, soil health and crop productivity.* Ph.D. thesis, Kerala Agricultural University, Thrissur. Ph.D. (Ag.) thesis, 289p.

Jackson ML (1958). *Soil Chemical Analysis.* Prentice Hall of India Pvt. Ltd., New Delhi, India.

Jackson ML (1973). *Soil Chemical Analysis (2nd Ed.).* Prentice Hall of India Pvt. Ltd., New Delhi, India.

Jones B, Haynes R, Phillips I (2010). "Effect of amendment of bauxite processing sand with organic materials on its chemical, physical and microbial properties." *Journal of Environmental Management*, **91**(11), 2281–2288.

KAU POP (2016). *Package of Practices Recommendations: Crops (15th Ed.).* Kerala Agricultural University, Thrissur.

Laird D, Fleming P, Davis D, Horton R, Wang B, Karlen D (2010). "Impact of biochar amendments on the quality of a typical midwestern agricultural soil." *Geoderma*, **158**, 443–449.

Lindsay WL, Norvell WA (1978). "Development of DTPA micronutrients soil test for zinc, iron, manganese and copper." *Soil Science Society of America Journal*, **42**, 421–428.

Mankasingh U, Choi P, Ragnarsdottir V (2011). "Biochar application in a tropical, agricultural region: A plot scale study in Tamil Nadu, India." *Applied Geochemistry*, **26**(8), 1594–1597.

Mohammed HM, Chandran J, Gopinath PP (2025). "RAISINS: Integrating R and AI for Agricultural Data Analysis." *Journal of Sustainable Technology in Agriculture*, **1**(1). doi:10.5281/zenodo.15622128.

Nagula S (2017). *Technology refinement for biochar production and evaluation of its effects on soil health and crop productivity.* Ph.D. thesis, Kerala Agricultural University, Thrissur. Ph.D. (Ag) thesis, 155p.

Nigussie A, Kissi E, Misganaw M, Ambaw G (2012). "Effect of biochar application on soil properties and nutrient uptake of lettuces (Lactuca sativa) grown in chromium polluted soils." *American-Eurasian Journal of Agricultural and Environmental Sciences*, **12**(3), 369–376.

Novak J, Busscher W, Laird D, Ahmedna M, Watts D, Niandou M (2009). "Impact of biochar amendment on fertility of a southeastern coastal plain soil." *Soil Science*, **174**(2), 105–112.

Punnoose A (2015). *Production, Characterisation and quality assessment of biochar.* Master's thesis, Kerala Agricultural University, Thrissur. M.Sc. (Ag) thesis, 88p.

Punnoose A, Anitha S (2015). "Production and characterisation of biochar from different organic materials." *Journal of Tropical Agriculture*, **53**(2), 191–196.

Salvacion S, Pangga G (2020). "Response of lowland rice grown in mine-contaminated soil with coconut husk and cattle manure biochars." *Rice-Based Biosystems Journal*, **7**, 1–12.

Singh R, Kaskaoutis D (2014). "Crop residue burning: a threat to South Asian air quality." *EOS Transactions*, **95**(37), 333–340.

Sombroek W, Nachtergaele F, Hebel A (1993). "Amounts, dynamics and sequestering of carbon in tropical and subtropical soils." *Journal of Human Environment Research and Management*, **22**(7), 417–426.

Subbiah B, Asija G (1956). "A rapid procedure for estimation of available nitrogen in soil." *Current Science*, **25**, 258–260.

Vikram K, Jayapal A, Pillai S, Isaac S, Mini V (2024). "Characterization of biochar produced from different agro-wastes." *Journal of Crop and Weed*, **20**(1), 12–20.

Walkley A, Black T (1934). "An examination of Degtjareff method for determining soil organic matter and proposed modification of the chromic acid titration method." *Soil Science*, **37**, 29–38.

Wang D, Li C, Parikh S, Scow K (2019). "Impact of biochar on water retention of two agricultural soils – a multiscale analysis." *Geoderma*, **340**, 185–191.

Zhang A, Bian R, Pan G, Cui L, Hussain Q, Li L, Zheng J, Zheng J, Zhang X, Han X, Yu X (2012). "Effects of biochar amendment on soil quality, crop yield and greenhouse gas emission in a Chinese rice paddy: a field study of two consecutive rice growing cycles." *Field Crops Research*, **127**, 153–160.

Zhang H, Chen C, Gray E, Boyd S, Yang H, Zhang D (2016). "Roles of biochar in improving phosphorus availability in soils: A phosphate adsorbent and a source of available phosphorus." *Geoderma*, **276**, 1–6.

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