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Influence of microbial enriched biochar as soil amendment on growth, yield and economics of okra (*Abelmoschus esculentus*) and soil fertility

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Abstract

A field experiment was conducted at BAIF Krishi Vigyan Kendra, Chaswad in the Bharuch district of Gujarat, to evaluate the effects of microbial-enriched biochar on the growth, yield and economics of okra, as well as its impact on soil properties and nutrient uptake under different fertilizer regimes. The study, carried out over two years (2023 and 2024), involved seven treatments combining microbial-enriched biochar with varying doses of farmyard manure (FYM) and recommended doses of fertilizers (RDF), arranged in a randomized block design.

Pooled data from the two years revealed that the application of 5 t ha⁻¹ biochar with 20 t ha⁻¹ FYM and 75% RDF significantly enhanced plant height (70.52 cm) at last picking, fruit weight per plant (233.20 g), number of fruits per plant (20.07) and pod yield (20.99 tha⁻¹) compared to RDF alone. Soil properties, including organic carbon, pH, and nutrient availability, improved with the application of enriched biochar and FYM. Nutrient uptake was also higher in treatments combining biochar with FYM. Economic analysis demonstrated that integrating biochar and FYM resulted in higher gross and net monetary returns, underscoring the sustainability and economic viability of this approach. The findings suggest that microbial-enriched biochar, when combined with organic amendments, can enhance soil health, improve crop productivity, and optimize economic returns in okra cultivation.

Keywords: Biochar, organic amendments, soil health, okra

Introduction

Intensive agriculture has significantly increased crop production, facilitated by the extensive use of modern inputs and practices. However, the excessive application of agrochemicals—often without considering soil potential—has accelerated soil degradation. Today, challenges such as soil degradation, climate variability, and the need for sustainable practices pose increasing threats to agricultural productivity. In this context, biochar emerges as a promising soil amendment.

Biochar is a stable, highly porous, carbon-rich material produced by the pyrolysis of plant or animal biomass at high temperatures (above 350–400 °C) under low oxygen conditions. It supplies essential soil nutrients, serves as a valuable source of organic matter, and contributes to soil carbon, which has been lauded for its potential in mitigating climate change through carbon sequestration (Pandit *et al.*, 2018) ^[13]. The addition of biochar to soils has gained attention as a strategy to enhance soil carbon sequestration and reduce atmospheric CO₂ concentrations (Lehmann, 2007) ^[7]. Enhanced carbon sequestration improves soil quality due to carbon's crucial role in physical, chemical, and biological soil processes.

Recent studies suggest that combining biochar with compost can further enhance soil fertility, boost plant growth, and increase carbon sequestration potential (Schulz *et al.*, 2013). For instance, Liu *et al.* (2012) ^[8] demonstrated that biochar, when applied with compost, synergistically improved soil organic matter, nutrient availability, and water-holding capacity under field conditions. Integrating biochar into conventional agricultural practices aligns with the goals of sustainable agriculture by improving soil properties and reducing dependency on chemical fertilizers. However, research on the combined effects of biochar and compost on soil fertility and crop performance remains limited. Despite its benefits, biochar lacks the biological activity necessary to significantly enhance soil fertility and

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support plant growth. Enriching biochar with beneficial microbial cultures addresses this limitation, transforming it into a carrier for microorganisms and facilitating their colonization in the soil. The combination of biochar's high surface area and microbial activity creates an optimal microenvironment that fosters root growth.

Okra (*Abelmoschus esculentus*), a widely cultivated vegetable, serves as both a vital food source and an economically important crop for smallholder farmers. However, its cultivation is often constrained by poor soil conditions and nutrient depletion. Okra is rich in essential vitamins and minerals such as calcium, phosphorus, magnesium, and iron, making it valuable for its anti-carcinogenic properties, immune-boosting capabilities, and anti-aging benefits (AVRDC, 1991) [2]. India leads global okra production, producing 6.37 million tonnes annually from over 0.52 million hectares, with a productivity rate of 12.3 t/ha (NHB, 2020–21). Given the significance of okra cultivation in India, this study was conducted to evaluate the efficacy of biochar in improving okra crop performance.

2. Materials and Methods

The study was conducted at BAIF Krishi Vigyan Kendra (KVK), Chaswad, in the Bharuch district of Gujarat during the summer seasons of 2023 and 2024. The experimental site is located at an altitude of 130 meters above mean sea level, with geographical coordinates of 21°34'43"N latitude and 73°21'08"E longitude. The region experiences summer temperatures reaching up to 40°C and winter temperatures dropping to approximately 17°C. The average annual rainfall is around 960 mm, predominantly occurring between June and September. The soil of the experimental field was clayey in texture. The field experiment was arranged in a Randomized Block Design (RBD) with seven treatments, each replicated three times. The plot size was standardized to 4.0 m × 3.0 m. The hybrid okra variety *Radhika* was sown in February of both years, maintaining a row spacing of 45 cm and an intra-row spacing of 15 cm, following standard agronomic practices. The recommended dose of fertilizer (RDF) was set at 100:75:75 kg ha⁻¹ of N:P:K, while Farm Yard Manure (FYM) was applied at a rate of 20 t ha⁻¹, with treatment-specific adjustments as outlined in Table 1. Given the climatic conditions, nine irrigations were applied throughout the growing period in both years. Okra pods were harvested 40–45 days after sowing.

Table 1: Treatment details

SN	Treatment Details
T ₁	: RDF (100:75:75 kg NPK/ha)
T ₂	: 5 t ha ⁻¹ Biochar + 0 t ha ⁻¹ FYM + 75% RDF
T ₃	: 5 t ha ⁻¹ Biochar + 20t ha ⁻¹ FYM + 75% RDF
T ₄	: 5 t ha ⁻¹ Biochar + 0 t ha ⁻¹ FYM + 100% RDF
T ₅	: 7.5 t ha ⁻¹ Biochar + 0 t ha ⁻¹ FYM + 75% RDF
T ₆	: 7.5 t ha ⁻¹ Biochar + 20t ha ⁻¹ FYM + 75% RDF
T ₇	: 7.5 t ha ⁻¹ Biochar + 0 t ha ⁻¹ FYM + 100% RDF

Biochar was prepared from *subabul* (*Leucaena leucocephala*) wood using a kiln combustion method. The resulting material was pulverized into powder using a pulverizer machine. The biochar was enriched with a microbial culture containing *Rhizobium*, Phosphate Solubilizing Bacteria (PSB), and *Trichoderma*. To prepare the enriched biochar, 20 liters of microbial solution was

mixed with 80 liters of water and applied to 100 kg of biochar. The treated biochar was shade-dried for 2–3 days before being applied to the field at rates of 5 and 7.5 t ha⁻¹, respectively.

Core soil samples were collected from a 0–20 cm depth before the trial and after the crop harvest to analyze chemical properties and fertility status, following standard procedures. The soil data from both years of the experiment were averaged and compiled into a table. After harvesting the okra, plant samples (pods and shoots) were collected, sun-dried, and subsequently oven-dried. These samples were digested in a di-acid mixture of nitric acid (HNO₃) and perchloric acid (HClO₄) and analyzed for nutrient uptake using standard methods. The data from plant sample analysis over the two years were averaged and presented in tabular form.

Economic parameters for each treatment combination were calculated based on prevailing market prices during 2023 and 2024. Growth and yield-related parameters were measured by selecting five plants randomly from each net plot area. All crop stands within the net plots were harvested separately according to their respective treatments, and the resulting yields were converted to a hectare basis and expressed in tonnes.

The statistical analysis of the collected data was performed using ANOVA at a 0.05 probability level to determine the significance of the results.

3. Results and Discussion

3.1 Effect of Microbial Enriched Biochar on Plant Height

Table 2 presents data on the effect of varying levels of microbial enriched biochar and recommended doses of chemical fertilizers, with and without FYM, on plant height at two different stages: the first and last picking, recorded over two years (2023 and 2024) as well as their pooled averages. The RDF only treatment showed the lowest plant height in both years (19.67 cm in 2023 and 24.87 cm in 2024), with a pooled average of 22.27 cm at first picking. In contrast, the highest plant height at first picking was observed in the 5 t ha⁻¹ microbial enriched biochar + 20 t ha⁻¹ FYM + 75% RDF treatment (T₃), which achieved 27.33 cm in 2023 and 32.63 cm in 2024, with a pooled average of 29.98 cm. This was statistically at par with treatment T₆ and significantly higher than the other treatments. A similar trend was noted at the last picking stage, where T₃ recorded the maximum plant height (66.30 cm in 2023 and 74.73 cm in 2024), with a pooled average of 70.52 cm. The study observed that increasing the rate of biochar application from 5 t ha⁻¹ to 7.5 t ha⁻¹ generally led to greater plant height, particularly when combined with FYM. While biochar alone improved plant height compared to the RDF-only treatment, the combination of biochar with FYM had an even more pronounced effect. This suggests a synergistic interaction that likely enhanced soil structure, nutrient availability and moisture retention. The increase in plant height can be attributed to the optimal availability of nutrients at critical crop growth stages, which may have promoted cell division and elongation, leading to increased plant height and dry matter accumulation. These findings align with those reported by Abbas *et al.* (2020) [1] and Verma *et al.* (2023) [15], who noted similar improvements in growth and yield attributes. Enhanced growth contributes to better photosynthetic partitioning and an improved source-sink

relationship, resulting in higher biomass production. Comparable results were also observed by Zhang *et al.* (2020) ^[16].

Table 2: Effect of microbial enrich biochar on plant height of Okra

Treatment	Plant Height (cm) at First Picking			Plant Height (cm) at Last Picking		
	2023	2024	Pooled	2023	2024	Pooled
T ₁	19.67	24.87	22.27	47.27	53.47	50.37
T ₂	19.00	24.00	21.50	61.00	60.90	60.95
T ₃	27.33	32.63	29.98	66.30	74.73	70.52
T ₄	24.33	29.09	26.71	64.47	69.57	67.02
T ₅	21.33	26.43	23.88	61.37	63.53	62.45
T ₆	23.67	31.17	27.42	64.73	72.70	68.72
T ₇	24.67	29.93	27.30	65.27	67.33	66.30
S.Em.±	1.58	1.50	1.09	2.71	2.60	1.88
C.D. at 5%	4.87	4.64	3.19	8.36	8.00	5.48

3.2 Effect of Microbial Enriched Biochar on Yield Attributes and Yield

Throughout the study years, graded doses of biochar combined with different fertility levels had a significant impact on the yield attributes of okra (Table 3). The T₃ treatment (5 t ha⁻¹ biochar + 20 t ha⁻¹ FYM + 75% RDF) consistently resulted in the highest fruit weight per plant (219.03 g in 2023 and 247.36 g in 2024) and the greatest number of fruits per plant (18.82 in 2023 and 21.32 in 2024), with similar trends observed in the pooled averages. These results were statistically at par with T₆ (7.5 t ha⁻¹ biochar + 20 t ha⁻¹ FYM + 75% RDF) and T₇ (7.5 t ha⁻¹ biochar + 100% RDF). In contrast, the lowest values for both yield parameters were recorded in the T₁ treatment (RDF only).The improved yield attributes can be attributed to the positive impact on root development, energy transformation and various metabolic processes in the plant. These enhancements facilitated better translocation of photosynthates towards sink development, ultimately boosting yield (Faloye *et al.*, 2019) ^[4].

The yield of okra was significantly affected by varying doses of biochar and fertility levels across both study years (Table 3). The T₃ treatment (5 t ha⁻¹ biochar + 20 t ha⁻¹ FYM + 75% RDF) led to a notable increase in pod yield by 86.6% in 2023 and 58.06% in 2024, compared to the RDF-only treatment (T₁). This increase was statistically at par with the T₆ treatment (7.5 t ha⁻¹ biochar + 20 t ha⁻¹ FYM + 75% RDF) and significantly higher than the other treatments. The pooled data also indicated that the highest pod yield was achieved with the T₃ treatment, followed by T₆ and T₇ (7.5 t ha⁻¹ biochar + 100% RDF).The significant improvements in yield attributes and overall yield observed in treatments with biochar and FYM can be attributed to the unique properties of biochar. Biochar's high surface area and porous structure enable it to adsorb and retain essential nutrients like nitrogen, phosphorus, and potassium, thereby reducing nutrient leaching. This enhances nutrient availability to maize plants, leading to healthier growth and improved yield (Meena and Prakasha, 2020; Gudade *et al.*, 2022) ^[10, 5]

Table 3: Effect of microbial enrich biochar on yield attributes and yield of Okra

Treat	Fruit Weight (gm) per Plant			No. Fruits per Plant			Pod Yield (tha ⁻¹)		
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T ₁	142.85	168.18	155.51	11.01	13.51	12.26	11.20	13.33	12.26
T ₂	148.51	175.84	162.17	11.59	14.09	12.84	12.25	16.57	14.41
T ₃	219.03	247.36	233.20	18.82	21.32	20.07	20.90	21.07	20.99
T ₄	154.03	180.03	167.03	12.15	14.65	13.40	12.62	17.22	14.92
T ₅	158.70	183.70	171.20	12.63	15.13	13.88	13.22	16.92	15.07
T ₆	214.22	240.89	227.55	18.32	20.82	19.57	20.29	20.56	20.42
T ₇	201.26	226.59	213.92	16.99	19.49	18.24	18.64	18.67	18.65
S.Em.±	7.94	8.55	5.83	0.70	0.91	0.57	0.66	0.96	1.02
C.D. at 5%	24.45	26.34	17.02	2.15	2.80	1.67	2.03	2.96	3.54

3.3 Effect of Microbial Enriched Biochar on Economics

The data presented in Table 4 highlights the impact of various soil amendment treatments on Gross Monetary Returns (GMR), Net Monetary Returns (NMR), and Benefit-Cost Ratio (BCR) over the years 2023 and 2024, along with pooled averages. The results indicate significant variations in GMR, NMR, and BCR among the different treatments applied. The treatment involving 5 t ha⁻¹ Biochar + 20 t ha⁻¹ FYM + 75% RDF consistently outperformed other treatments, achieving the highest averages of ₹ 419753 ha⁻¹ for GMR, ₹ 299176 ha⁻¹ for NMR, and a BCR of 3.48 over the two-year period. This highlights the economic advantage of integrating biochar and farmyard manure

(FYM) with reduced fertilizer doses, promoting higher profitability and sustainability in crop production. Additionally, the Recommended Dose of Fertilizers (RDF), which entails applying 100:75:75 kg NPK ha⁻¹, also showed a competitive BCR of 3.13, indicating that while traditional fertilizer use remains economically viable, the integration of biochar and organic amendments can significantly enhance returns. These findings suggest that incorporating biochar and FYM not only boosts soil health but also optimizes economic returns, presenting a more sustainable approach compared to conventional fertilization practices. Similar findings were reported by Madhavi *et al.* (2017) ^[9] and Keske *et al.* (2020) ^[6].

3.4 Effect of Microbial Enriched Biochar on Soil Properties

The table 5 highlights the changes in soil properties after the application of various soil amendment treatments. The soil pH across all treatments ranged from 7.15 to 7.28, indicating a slight shift towards alkalinity compared to the initial pH of 6.62. Electrical Conductivity (EC) varied slightly among treatments, with values between 0.23 and 0.34 dSm⁻¹, indicating that all treatments maintained EC within acceptable levels for crop growth. Organic Carbon content increased with the addition of biochar and FYM, enhancing soil organic matter. The highest O.C. percentage (0.80%) was achieved with the application 5 t ha⁻¹ Biochar + 20 t ha⁻¹ FYM + 75% RDF, showing a significant improvement from the initial value of 0.50%. This suggests that incorporating biochar and FYM can enhance soil organic matter, thereby improving soil health and fertility. The improved soil pH in biochar-treated plots can be attributed to the release of basic cations from the biochar. These cations can participate in exchange reactions, replacing exchangeable aluminium and hydrogen ions on the soil's exchange complex. This process decreases soil exchangeable acidity, thereby enhancing soil pH in acidic conditions. Similar results were reported. The highest carbon content in biochar-amended plots might be responsible for organic carbon build-up and also attributed to the very low level degradation and recalcitrant nature of biochar in soil.

The application of biochar and FYM significantly enhanced soil nutrient availability. The treatment with 5 t ha⁻¹ Biochar + 20 t ha⁻¹ FYM + 75% RDF showed the highest nitrogen (342.47 kg/ha) and zinc (2.02 ppm) levels. The 7.5 t ha⁻¹ Biochar + 20 t ha⁻¹ FYM + 75% RDF treatment achieved

the highest phosphorus (95.83 kg ha⁻¹), potassium (220.69 kg ha⁻¹), and iron (3.11 ppm) availability. Manganese peaked at 7.86 ppm with the recommended NPK dose. These findings suggest that biochar and FYM combinations effectively improve soil nutrient status.

3.4 Effect of Microbial Enriched Biochar on Plant Uptake

It is evident from the data shown in Table 6 that considerably higher N, P and K uptake was recorded in 5 t ha⁻¹ biochar and 20 t ha⁻¹ FYM with 75% RDF over rest of the treatments. The RDF (100:75:75 kg NPKha⁻¹), yielding a nitrogen, phosphorus and potassium value of 12.23%, with levels at 1.96%, 1.07%, and 0.69%, respectively. The combination of 5 t ha⁻¹ biochar with 20 t ha⁻¹ FYM and 75% RDF significantly increased nutrient levels, showing the highest nitrogen (2.18%), phosphorus (1.22%), and potassium (0.74%) among all treatments. In contrast, treatments with higher biochar doses (7.5 t ha⁻¹) and no FYM showed reduced nutrient availability, particularly when combined with 100% RDF, where nitrogen dropped to 1.71%. This suggests that the integration of biochar with FYM enhances nutrient retention and availability, while excessive biochar application without FYM may lead to imbalances. These findings highlight the importance of combining biochar with organic amendments like FYM to optimize soil fertility. Improvement in plant nutrient content could be ascribed to combined effect of biochar and FYM, which increased the availability of nutrients in the soil and more absorption of nutrients by the crop. The finding was analogous with Meena and Prakasha (2020) ^[10] and Nimbalkar *et al.* (2023) ^[12].

Table 4: Effect of microbial enrich biochar on economics of Okra

Treatment	Gross Monetary Returns (₹ha ⁻¹)			Cost of Cultivation (₹ha ⁻¹)	Net Monetary Returns (₹ha ⁻¹)			Benefit: Cost Ratio		
	2023	2024	Pooled		2023	2024	Pooled	2023	2024	Pooled
T ₁	223912	266667	245289	78335	145577	188332	166954	2.86	3.40	3.13
T ₂	245011	331333	288172	110577	134434	220756	177595	2.22	3.00	2.61
T ₃	418100	421407	419753	120577	297523	300830	299176	3.47	3.49	3.48
T ₄	252421	344363	298392	111668	140752	232695	186724	2.26	3.08	2.67
T ₅	264315	338307	301311	127244	137072	211063	174067	2.08	2.65	2.36
T ₆	405839	411161	408500	137244	268595	273917	271256	2.96	3.00	2.98
T ₇	372794	373333	373064	128335	244460	244998	244729	2.90	2.91	2.91
S.Em.±	13196	19235	20442		13196	19235	20442	0.11	0.13	0.18
C.D. at 5%	40663	59274	70742		40663	59274	70742	0.35	0.39	0.63

Table 5: Effect of microbial enrich biochar on soil properties

	pH	EC (dsm ⁻¹)	O.C. (%)	N (kg ha ⁻¹)	P ₂ O ₅ (kg ha ⁻¹)	K ₂ O (kg ha ⁻¹)	DTPA Extractable (ppm)			
							Fe	Mn	Zn	Cu
Initial	6.62	0.29	0.50	305.79	46.02	117.25	1.91	7.09	0.79	1.59
T ₁	7.23	0.34	0.60	320.88	88.81	187.50	2.53	7.86	1.43	1.97
T ₂	7.20	0.34	0.58	315.96	90.03	198.78	2.98	6.73	1.53	1.84
T ₃	7.18	0.30	0.80	342.47	89.63	216.59	2.73	7.02	2.02	2.05
T ₄	7.28	0.24	0.69	319.59	86.71	199.78	2.74	7.40	1.71	2.40
T ₅	7.15	0.34	0.63	317.30	81.87	197.10	2.82	7.02	1.68	2.05
T ₆	7.15	0.33	0.59	329.05	95.83	220.69	3.11	7.13	1.87	2.22
T ₇	7.16	0.23	0.64	311.79	88.76	213.31	2.74	7.16	1.99	1.63

Table 6: Effect of biochar on plant uptake

Treatments	Uptake by plant (%)		
	Nitrogen	Phosphorus	Potassium
T ₁	1.96	1.07	0.69
T ₂	2.00	1.01	0.65
T ₃	2.18	1.22	0.74
T ₄	1.95	0.97	0.58
T ₅	2.15	1.13	0.60
T ₆	1.81	0.72	0.55
T ₇	1.71	1.13	0.70

Conclusion

The study concludes the significant benefits of integrating microbial-enriched biochar and farmyard manure (FYM) with reduced fertilizer doses on the growth, yield, and soil health of okra. The treatment comprising 5 t ha⁻¹ biochar + 20 t ha⁻¹ FYM + 75% recommended dose of fertilizers (RDF) consistently demonstrated superior performance, achieving the highest plant height, fruit weight, pod yield, and economic returns. This treatment also led to notable improvements in soil properties, including enhanced organic carbon content, increased nutrient availability, and optimized soil pH.

These findings emphasize the critical role of combining biochar with organic amendments to optimize nutrient uptake and promote sustainable agricultural productivity. Integrating biochar and FYM offers a viable, eco-friendly approach to enhancing crop yields, boosting economic returns, and improving soil health, aligning with global efforts to advance sustainable farming practices.

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