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STUDIES ON COMPARATIVE ADVANTAGE OF BIOCHAR AND ZEOLITE ON GROWTH OF GINGER (*Zingiber officinale* ROSCOE.)

Nymisha Pemmaraju[1]*, Rajasekhar Marri[2], Veena Joshi[3], V. Krishnaveni[4] and R. Preetham Goud[5]

[1]Department of Plantation, Spices, Medicinal and Aromatic crops, PGIHS, SKLTGHU, Mulugu, Siddipet-502 279, Telangana, India.

[2]Department of Horticulture, PGIHS, SKLTGHU, Mulugu, Siddipet - 502 279, Telangana, India.

[3]College of Horticulture, Mojerla, Sri Konda Laxman Telangana SKLTGHU, Telangana, India.

[4]Medicinal and Aromatic Plants Research Station (MAPRS), Rajendranagar, Hyderabad, Telangana, India.

[5]College of Horticulture, Malyal, Sri Konda Laxman Telangana Horticultural University, Telangana, India.

*Corresponding author E-mail : nymishapemmaraju@gmail.com

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ABSTRACT

The present investigation, entitled "Studies on the Comparative Advantage of Biochar and Zeolite on the Growth of Ginger (*Zingiber officinale* Roscoe.)", was conducted during *Kharif* 2025 at Sri Konda Laxman Telangana Horticultural University, Mulugu, using a Factorial Randomized Block Design (FRBD) with 14 treatment combinations comprising seven soil amendment treatments (biochar, zeolite and control) and two nutrient levels (75% and 100% recommended N & K), replicated thrice. Soil amendments and nutrient levels significantly influenced ginger growth. The treatment combination Biochar @ 4 t/ha and100% recommended N & K (A_3L_2) recorded the highest plant height (78.33 cm), number of leaves (50.67), leaf length (45.53 cm), leaf width (6.23 cm), leaf area (56.59 cm^2) and leaf area index (5.15) at 135 DAS. Among the main effects, Biochar @ 4 t/ha (A_3) produced the highest sprouting percentage (88.89%), plant spread, tillers per plant (5.52), chlorophyll content (9.98), stem length (51.65 cm) and stem diameter (6.88 cm). The 100% recommended N & K level also significantly improved all growth parameters compared with 75% recommended N & K. The study demonstrates that Biochar @ 4 t/ha combined with 100% recommended N & K is the most effective treatment for enhancing ginger growth under the Central Telangana agro-climatic conditions.

Key words : Ginger, Soil amendments, Biochar, Zeolite, Vegetative growth.

Introduction

Ginger (*Zingiber officinale* Roscoe.) is one of the most important spice crops cultivated worldwide for its culinary, medicinal and industrial uses. India is the leading producer, consumer and exporter of ginger, with a production of 2.22 million tonnes from 204.8 thousand ha and an average productivity of 10.86 t/ha Soni *et al.* (2023). Ginger rhizomes are valued for their characteristic flavour and aroma, which are mainly attributed to volatile oils and gingerols and possess several pharmacological properties including antioxidant, anti-inflammatory, antidiabetic and anticancer activities Ali *et al.* (2024). Ginger is cultivated in considerable area in Telangana, particularly in Sangareddy and Vikarabad districts, owing to its high market demand in the state and economic importance Nandam *et al.* (2023).

Ginger is an exhaustive crop with a high demand for nutrients throughout its growth period. However, continuous dependence on inorganic fertilizers alone may deteriorate soil health by reducing soil organic carbon, microbial activity and nutrient-use efficiency Kandiannan *et al.* (2022). Integrated nutrient management practices involving organic amendments have been shown to improve soil properties and sustain crop productivity Divyashree *et al.* (2022).

Among the emerging soil amendments, biochar and zeolite have gained considerable attention because of their ability to improve soil physical, chemical and biological properties. Biochar, a carbon-rich material produced through the pyrolysis of biomass, enhances soil structure,

water-holding capacity, cation exchange capacity and nutrient retention (Chen, Zhou and Zhu, 2008). Zeolite, a naturally occurring crystalline aluminosilicate mineral, improves soil moisture retention, hydraulic conductivity and nutrient availability while reducing nutrient losses through its high cation exchange capacity Gholizadeh-Sarabi and Sepaskhah (2013), Szerement *et al.* (2021), Kukowska *et al*. (2025).

Although, the beneficial effects of biochar and zeolite on soil quality have been reported, comparative information on their influence on the growth of ginger under different nutrient levels is limited. Therefore, the present study was undertaken to evaluate the comparative advantage of biochar and zeolite, in combination with recommended nitrogen and potassium levels, on the growth of ginger under the Central Telangana agro-climatic conditions.

Materials and Methods

A field experiment was conducted during *Kharif* 2025-2026 at the University Farm, PGIHS, SKLTGHU, Mulugu, Siddipet district, Telangana, India. The experimental site is situated at an altitude of 612 m above mean sea level, with geographical coordinates of 17°43′ 02″ N latitude and 78°37′ 34″ E longitude, falling under the Central Telangana Agro-climatic Zone. The experiment was laid out in a Factorial Randomized Block Design (FRBD) with two factors and three replications. Factor I consisted of seven soil amendment treatments, *viz*., Biochar @ 2, 3 and 4 t/ha, Zeolite @ 1, 1.5 and 2 t/ha and control (without soil amendment), while Factor II consisted of two nutrient levels, *viz*., 75 and 100% recommended dose of nitrogen and potassium (75 kg N and 50 kg K/ha RDF). Phosphorus was applied uniformly @ 50 kg P/ha to all the treatments.

The spacing adopted was 30 × 20 cm, accommodating 54 plants per plot. Ginger rhizomes of cv. Maran were planted on raised beds. Enriched biochar and zeolite were applied as basal treatments as per the treatment schedule, while nitrogen and potassium were applied according to the recommended schedule. Observations on sprouting and growth were recorded at 90 and 135 DAS. The data were statistically analysed following the procedure of analysis of variance (ANOVA) for a Factorial Randomized Block Design as described by Panse and Sukhatme (1985).

Results and Discussion

Percent sprouting (%)

Among the soil amendments, biochar @ 4 t/ha (A_3) recorded the highest sprouting percent (88.89%), followed by A_2, A_6, A_5, A_1 and A_4 (86.42, 84.57, 81.17, 80.69 and 78.70%, respectively), whereas the lowest sprouting percent (67.59%) was recorded in the control (A_7). Among the nutrient levels, application of 100% recommended nitrogen and potassium (L_2) recorded the highest sprouting percent (84.16%), while the lowest (78.13%) was observed with 75% recommended nitrogen and potassium (L_1). However, the differences among the soil amendments, nutrient levels and their interaction were statistically non-significant, indicating that the treatments did not exert a significant influence on sprouting percentage.

Plant height (cm)

Over the course of the study, plant height measured at 135 DAS varied significantly due to different soil amendments and nutrient levels. Biochar @ 4 t/ha (A_3) recorded the maximum plant height (73.36 cm), while the control (A_7) recorded the minimum (24.98 cm). Application of 100% recommended N & K (L_2) resulted in higher plant height (64.70 cm) than 75% recommended N & K (L_1), which was (55.51 cm). Among the interactions, A_3L_2 (Biochar @ 4 t/ha and 100% N & K) consistently recorded the highest plant height (78.33 cm). The increased plant height may be attributed to enhanced root development and efficient translocation of water and nutrients, which promoted cell division, cell elongation and overall vegetative growth in ginger. These findings are in agreement with the reports of Adekiya *et al*. (2020), Jabin and Rani (2024).

Plant spread (N-S)

Plant spread (N-S) at 135 DAS was maximum in biochar @ 4 t/ha (32.18 cm), while the control (A_7) recorded the minimum (20.23 cm). Among the nutrient levels, application of 100% recommended N & K (L_2) recorded the highest plant spread (26.31 cm), whereas the lowest (21.48 cm) was recorded with 75% recommended N & K (L_1). However, the differences among the soil amendments, nutrient levels and their interaction were statistically non-significant, indicating that the treatments did not exert a significant influence on plant spread (N-S).

Plant spread (E-W)

Among the soil amendments, biochar @ 4 t/ha recorded the maximum plant spread (32.51 cm) at 135 DAS, while the control (A_7) recorded the minimum plant spread (16.56 cm). Among the nutrient levels, application of 100% recommended N & K (L_2) recorded the highest plant spread (25.55 cm), whereas the lowest (21.79 cm) was recorded with 75% recommended N & K (L_1). However, the differences among the soil amendments, nutrient levels, and their interaction were statistically non-

Table 1 : Effect of soil amendments and nutrient levels and their interaction on plant height (cm) of ginger.

N & K levels (L)	Soil amendments (A)							Mean (L)
	A_1	A_2	A_3	A_4	A_5	A_6	A_7	
L_1	62.60	65.03	68.40	60.90	55.17	57.95	18.53	**55.51**[a]
L_2	67.47	73.30	78.33	66.33	66.78	69.32	31.43	**64.70**[a]
Mean (A)	**65.03**[ab]	**69.16**[a]	**73.36**[a]	**63.61**[bc]	**60.97**[c]	**63.63**[bc]	**24.98**[d]	
Factors	**Factor (A)**		**Factor (L)**		**Factor (AxL)**			
SE(m)±	**2.56**		**1.36**		**3.62**			
CD@5%	**7.44**		**3.97**		**10.52**			

Table 2 : Effect of soil amendments and nutrient levels and their interaction on total number of leaves of ginger.

N & K levels (L)	Soil amendments (A)							Mean (L)
	A_1	A_2	A_3	A_4	A_5	A_6	A_7	
L_1	27.33	38.33	35.33	26.00	31.33	37.67	19.33	**30.76**[b]
L_2	32.67	42.33	50.67	34.33	40.67	48.00	20.47	**38.44**[a]
Mean (A)	**30.00**[c]	**40.33**[a]	**43.00**[a]	**30.16**[c]	**36.00**[b]	**42.83**[a]	**19.90**[d]	
Factors	**Factor (A)**		**Factor (L)**		**Factor (AxL)**			
SE(m)±	**1.29**		**0.69**		**1.83**			
CD@5%	**3.76**		**2.02**		**5.32**			

significant, indicating that the treatments did not exert a significant influence on plant spread (E-W).

Number tillers per plant

Among the soil amendments, biochar @ 4 t/ha (A_3) recorded the maximum number of tillers per plant (5.52) at 135 DAS, while the control (A_7) recorded the minimum (2.24). Among the nutrient levels, application of 100% recommended N & K (L_2) recorded the highest number of tillers per plant (4.86), whereas the lowest (4.20) was recorded with 75% recommended N & K (L_1). However, the differences among the soil amendments, nutrient levels and their interaction were statistically non-significant, indicating that the treatments did not exert a significant influence on number of tillers per plant.

Total number of leaves per plant

Throughout the study, number of leaves per plant showed significant variation due to different soil amendments and nutrient levels. Biochar @ 4 t/ha (A_3) recorded the maximum number of leaves per plant (43.00), while the control (A_7) recorded the minimum (19.90). Among the nutrient levels, application of 100% recommended N & K (L_2) recorded the highest number of leaves per plant (38.44), whereas the lowest (30.76) was recorded with 75% recommended N & K (L_1). A_3L_2 (Biochar @ 4 t/ha and 100% N & K) recorded the highest number of leaves per plant (50.67). The improvement in leaf production could be associated with the ability of biochar to improve root growth and nutrient absorption, thereby promoting greater photosynthetic activity and the formation of new leaves throughout the crop growth period which were in agreement with Adekiya *et al*. (2020).

Average leaf length (cm)

Biochar @ 4 t/ha (A_3) recorded the maximum leaf length (41.10 cm), while the control (A_7) recorded the minimum leaf length (30.09 cm). Application of 100% recommended N & K (L_2) recorded the highest leaf length (37.64 cm), whereas the lowest (35.12 cm) was recorded with 75% recommended N & K (L_1). Among the interactions A_3L_2 (Biochar @ 4 t/ha and 100% N & K) recorded the maximum leaf length (45.53 cm). The increased leaf length under biochar and zeolite application may be attributed to improved soil physical conditions that encouraged vigorous root development and enhanced water uptake, thereby promoting cell expansion and leaf elongation as reported by Jabborova *et al*. (2021).

Average leaf width (cm)

The treatment biochar @ 4 t/ha (A_3) recorded the maximum leaf width (5.52 cm), while the control (A_7) recorded the minimum leaf width (2.73 cm). Application of 100% recommended N & K (L_2) recorded the highest leaf width (4.80 cm), whereas the lowest (4.03 cm) was recorded with 75% recommended N & K (L_1). Biochar @ 4 t/ha and 100% N & K recorded the maximum leaf width (6.23 cm). The enhanced leaf width may be due to

Table 3 : Effect of soil amendments and nutrient levels and their interaction on average leaf length (cm) of ginger.

N & K levels (L)	Soil amendments (A)							Mean (L)
	A_1	A_2	A_3	A_4	A_5	A_6	A_7	
L_1	35.15	38.86	36.67	36.53	32.34	37.92	28.39	**35.12**[a]
L_2	36.32	36.76	45.53	33.77	39.09	40.25	31.79	**37.64**[a]
Mean (A)	**35.73**[b]	**37.81**[ab]	**41.10**[a]	**35.15**[b]	**35.71**[b]	**39.08**[ab]	**30.09**[c]	
Factors	**Factor (A)**		**Factor (L)**		**Factor (AxL)**			
SE(m)±	**1.24**		**0.66**		**1.76**			
CD@5%	**3.62**		**1.93**		**5.12**			

Table 4 : Effect of soil amendments and nutrient levels and their interaction on average leaf width (cm) of ginger.

N & K levels (L)	Soil amendments (A)							Mean (L)
	A_1	A_2	A_3	A_4	A_5	A_6	A_7	
L_1	3.63	4.70	4.82	2.70	4.07	4.87	2.47	**4.03**[a]
L_2	4.40	5.60	6.23	4.37	5.03	6.00	3.00	**4.80**[a]
Mean (A)	**4.01**[cd]	**5.15**[ab]	**5.52**[a]	**3.53**[de]	**4.55b**[c]	**5.43**[a]	**2.73**[e]	
Factors	**Factor (A)**		**Factor (L)**		**Factor (AxL)**			
SE(m) ±	**0.34**		**0.18**		**0.48**			
CD@5%	**0.99**		**0.52**		**1.40**			

improved physiological efficiency and balanced nutrient uptake under biochar and zeolite application, resulting in better leaf development and expansion in ginger and similar observations were reported by Setyawati *et al*. (2023).

Average Leaf area (cm²)

Biochar @ 4 t/ha recorded the maximum leaf area (48.55 cm²), while the control (A_7) recorded the minimum leaf area (37.34 cm²). Application of 100% recommended N & K (L_2) recorded the highest leaf area (46.02 cm²), whereas the lowest (42.50 cm²) was recorded with 75% recommended N & K (L_1). Biochar @ 4 t/ha and 100% N & K recorded the maximum leaf area (56.59 cm²). The increased leaf area may be attributed to improved cell division and expansion, resulting in the development of larger photosynthetic surfaces under biochar and zeolite application these findings are in agreement with Kwizera *et al*. (2023).

Leaf area index (LAI)

The observations on leaf area index at 135 DAS revealed that biochar @ 4 t/ha (A_3) recorded the maximum leaf area index (4.14), followed by A_1 (3.80), A5 (3.73) and A_6 (3.70), which were on par with A_3, while the control (A_7) recorded the minimum leaf area index (1.94). Among the nutrient levels, application of 100% recommended N & K (L_2) recorded the highest leaf area index (3.70), whereas the lowest (3.16) was recorded with 75% recommended N & K (L_1). The interactions revealed the treatment A_3L_2 (Biochar @ 4 t/ha and 100% N & K) recorded the maximum leaf area index (5.15), while the lowest (1.85) was recorded in A_7L_1. These differences in leaf area index may be attributed to enhanced leaf expansion and greater canopy development under biochar application, while adequate nutrient supply further promoted vegetative growth as reported by *et al*. (2021).

Chlorophyll content (SPAD)

Chlorophyll content at 135 DAS exhibited significant differences among the soil amendments and nutrient levels. Among the soil amendments, biochar @ 4 t/ha (A_3) recorded the maximum chlorophyll content (9.98), while the control (A_7) recorded the minimum chlorophyll content (7.36). Among the nutrient levels, application of 100% recommended N & K (L_2) recorded the highest chlorophyll content (9.50), whereas the lowest (9.01) was recorded with 75% recommended N & K (L_1). However, the differences among the soil amendments, nutrient levels and their interaction were statistically non-significant, indicating that the treatments did not exert a significant influence on chlorophyll content.

Average stem length (cm)

Stem length at 135 DAS showed significant variation among the soil amendments and nutrient levels. Among the soil amendments, biochar @ 4 t/ha (A_3) recorded the

Table 5 : Effect of soil amendments and nutrient levels and their interaction on average leaf area (cm^2) of ginger.

N & K levels (L)	Soil amendments (A)							Mean (L)
	A_1	A_2	A_3	A_4	A_5	A_6	A_7	
L_1	45.90	43.03	40.51	36.45	45.25	43.38	30.00	**42.50**[a]
L_2	46.90	48.12	56.59	38.96	46.15	48.75	36.69	**46.02**[a]
Mean (A)	**44.90**[a]	**45.57**[ab]	**48.55**[a]	**37.70**[b]	**45.70**[ab]	**46.06**[ab]	**37.34**[b]	
Factors	**Factor (A)**		**Factor (L)**		**Factor (AxL)**			
SE(m) ±	**1.84**		**0.98**		**2.61**			
CD@5%	**5.37**		**2.87**		**7.60**			

Table 6 : Effect of soil amendments and nutrient levels and their interaction on average leaf area index (LAI) of ginger.

N & K levels (L)	Soil amendments (A)							Mean (L)
	A_1	A_2	A_3	A_4	A_5	A_6	A_7	
L_1	3.84	3.33	3.14	2.88	3.75	3.34	1.85	**3.16**[a]
L_2	3.76	3.97	5.15	3.21	3.72	4.06	2.04	**3.70**[a]
Mean (A)	**3.80**[a]	**3.65**[b]	**4.14**[a]	**3.04**[c]	**3.73**[ab]	**3.70**[ab]	**1.94**[d]	
Factors	**Factor (A)**		**Factor (L)**		**Factor (AxL)**			
SE(m) ±	**0.15**		**0.08**		**0.22**			
CD@5%	**0.46**		**0.24**		**0.65**			

maximum stem length (51.65 cm), while the control (A_7) recorded the minimum stem length (42.89 cm). Among the nutrient levels, application of 100% recommended N & K (L_2) recorded the highest stem length (47.23 cm), whereas the lowest (42.78 cm) was recorded with 75% recommended N & K (L_1). However, the differences among the soil amendments, nutrient levels, and their interaction were statistically non-significant, indicating that the treatments did not exert a significant influence on stem length.

Average stem diameter (cm)

Significant differences in stem diameter at 135 DAS were observed among the soil amendments and nutrient levels. Among the soil amendments, biochar @ 4 t/ha (A_3) recorded the maximum stem diameter (6.88 cm), while the control (A_7) recorded the minimum stem diameter (5.48 cm). Among the nutrient levels, application of 100% recommended N & K (L2) recorded the highest stem diameter (6.53 cm), whereas the lowest (6.13 cm) was recorded with 75% recommended N & K (L_1). However, the differences among the soil amendments, nutrient levels, and their interaction were statistically non-significant, indicating that the treatments did not exert a significant influence on stem width.

Conclusion

The present investigation demonstrated that soil amendments and nutrient levels significantly influenced the growth of ginger under Central Telangana conditions. Among the treatments, biochar @ 4 t/ha in combination with 100% recommended nitrogen and potassium consistently recorded superior performance for most of the growth parameters. The improved performance may be attributed to enhanced soil physical properties and moisture retention, which promoted better crop growth and productivity. Therefore, the application of biochar @ 4 t/ha along with 100% recommended nitrogen and potassium can be recommended as an effective nutrient management strategy for improving ginger production under Central Telangana conditions.

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