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Effect of Recommended and Graded Doses of Biochar with and without ZMB Biofertilizer and Zinc on the Growth Attributes of Rice (*Oryza sativa* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted during the Kharif seasons of 2022 and 2023 at the Students' Instructional Farm, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj Ayodhya, to assess the impact of graded doses of biochar, varying fertility levels, and the addition of biofertilizers and zinc on rice cultivation under partially reclaimed sodic soils. Nine treatments were applied, including combinations of recommended doses of fertilizers (RDF), biochar (5 t ha^{-1} and 2.5 t ha^{-1}), biofertilizer (ZMB), and zinc sulphate ($ZnSO_4$) in a randomized block design with three replications. The treatments were: T_1 (Control), T_2 (100% RDF), T_3 (50% RDF), T_4 (50% RDF + 5 t ha^{-1} biochar), T_5 (50% RDF + 5 t ha^{-1} biochar + ZMB), T_6 (50% RDF + 5 t ha^{-1} biochar + ZMB + $ZnSO_4$), T_7 (100% RDF + 2.5 t ha^{-1} biochar), T_8 (100% RDF + 2.5 t ha^{-1} biochar + ZMB), and T_9 (100% RDF + 2.5 t ha^{-1} biochar + ZMB + $ZnSO_4$). The rice variety NDR 2065 was used as the test crop. Growth parameters such as plant height, dry matter accumulation, root length, root volume, number of tillers, and panicle length were evaluated. The results showed that the treatment T_9 (100% RDF + 2.5 t ha^{-1} biochar + ZMB + $ZnSO_4$) produced the highest growth and quality parameters, indicating a significant improvement in rice performance. The study suggests combining biochar, biofertilizers, and zinc under reduced fertilizer levels can enhance rice growth and productivity in sodic soils, offering a sustainable approach to soil fertility management.

Keywords: Kharif; plant height; ZnSO4; ZMB; growth attributes; rice; biofertilizer.

1. INTRODUCTION

Rice *(Oryza sativa* L*.)* is the most important cereal crop grown under aquatic conditions and mostly under submergence or variable ponding conditions. It belongs to the family *Poaceae (Gramineae).* It is the most important staple food of about more than 60% of the total world population. The production of rice in the world is about 509.26 million metric tons with a productivity of 4.60 metric tons ha^{-1}, an area of 165.21 million ha (Anonymous, 2021- 2022). In India, rice is cultivated in 450.57 Lakh ha with an annual production of 122.27 million tons and average productivity of 2713 kg ha^{-1} (*Anonymous*, 2022). Uttar Pradesh is the largest rice-growing state after West Bengal. In Uttar Pradesh, the area under rice cultivation is about 59.70 lakh ha. and the production was about 159.68 Lakh MT with a productivity of 26.75 q ha^{-1}. (Anonymous, 2022). Indo-Gangetic and other river-side states like West Bengal, Uttar Pradesh, Bihar, Punjab, Haryana, Odisha, Chhattisgarh, Andhra Pradesh, Telangana, Tamil Nadu, Kerala, Assam, and others are major rice-producing states in India. Punjab has experienced excellent prosperity in rice cultivation during the last 60 years since the Green Revolution began in India in the 1960s. Generally, Rice crop requires hot and humid weather, plentiful water supply, and abundant sunshine. Ideal temperature ranges from 20 ^{0}C to 40 ^{0}C and ideal rainfall ranges from 100 to 200 cm.

Biochar (BC) is the carbon-rich product obtained when biomass, such as wood, manure, or leaves, is heated in a closed container with little or no available air. In more technical terms, BC is produced by the so-called thermal decomposition of organic material under a limited supply of oxygen (O_2) and at relatively low temperatures. The addition of BC to agricultural soils has been projected as a means to improve soil fertility and mitigate climate change. It is indicated that amending BC into soil improves the structure and properties of soil, such as the water-holding capacity, organic matter content, aeration condition, pH value, cationic exchange capacity (CEC), and the formation of aggregates of soil. The leaching losses of nitrogen and phosphorous in soil and the releases of greenhouse gases (N_2O and CH_4) from soil could be decreased in the presence of BC. In addition, BC has a porous structure, charged surface, and surface functional groups (such as carboxyl, hydroxyl, phenolic hydroxyl, and carbonyl groups). These properties are the important factors that influence the migration, transformation, and bioavailability of contaminants in soil. The application of Biochar improves soil fertility through two mechanisms: adding nutrients to the soil (such as K, to a limited extent P, and many micronutrients) or retaining nutrients from other sources, including nutrients from the soil itself. Furthermore, the application of Biochar to soils has been identified as a low-cost technology that can stabilize organic carbon, reduce greenhouse gas emissions, improve soil physical and chemical properties, and boost crop yield productivity and farm incomes. Biochar application can lead to a reduction in inorganic fertilizer use by farmers. The sole Biochar application, in most cases, did not provide any substantial amount of nutrients.

2. MATERIALS AND METHODS

The experiments were conducted at the Student's Instructional Farm of Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya situated on Ayodhya-Raebareli Road about 42 km from Ayodhya. The experimental site falls under the subtropical climatic zone of Indo-Gangetic plains located at 26.54^0 N latitude, 81.82^0 E longitudes, and an altitude of 113 meters above mean sea level. The district Ayodhya falls under a sub-humid climate, receiving a mean annual rainfall of about 1200 mm. About 85% of the total rainfall is received from mid-June to the end of September. However, occasional showers are also common during the winter. The winter months are cold, and an occasional frost occurs during this period. The NDR 2065 variety of rice were taken for the study. The treatments used in the study were: T_1 (Control), T_2 (100% RDF), T_3 (50% RDF), T_4 (50% RDF + 5 t ha^{-1} Biochar), T_5 (50% RDF + 5 t ha^{-1} Biochar + ZMB), T_6 (50% RDF + 5 t ha^{-1} Biochar + ZMB + Zn), T_7 (100% RDF + 2.5 t ha^{-1}Biochar), T_8 (100% RDF + 2.5 t ha^{-1} Biochar + ZMB), and T_9 (100% RDF + 2.5 t ha^{-1} Biochar + ZMB + Zn). Observations taken for study are plant height, dry matter accumulation, root length, root volume, no. of tillers, length of panicle, were recorded during the investigation. The experiment was done using a randomized block design and data was analyzed using OPState Software.

3. RESULTS AND DISCUSSION

The data regarding plant height is presented in Table 1 and Fig. 1 at different growth stages, 30 DAT, 60 DAT, 90 DAT, and at harvest stage. Treatment incorporating biochar (T_4-T_9) consistently exhibited higher plant heights compared to the control treatment (T_1). In control at 30 DAT in 2022 and 2023 had a plant height of 30.9 cm and 32.2 cm respectively, while treatment T_2 (100% RDF100:60:40, N P_2O_5, K_2O) had a plant height of 34.5 cm and 35.9 cm for both years and T_3 (50 % RDF) had a plant height 33.5 cm and 34.5 cm for both the years respectively. However, the maximum plant height was recorded with the application of T_9 (38.9 cm and 40.1 cm) for both years. This trend was evident throughout all growth stages in both years of experimentation, highlighting the positive impact of biochar on plant height. In T_7 (100 % RDF + 2.5 t/ha-1 Biochar) and T_9 (100 % RDF + 2.5 t ha^{-1} Biochar + ZMB + Zn) at 60 DAT in 2022 had a plant height of 57.5 cm and 61.8 cm respectively, and in 2023 T_7 and T_9 had a plant height of 59.5 and 63.8 respectively. while T_4 (50 % RDF + 5 t ha^{-1} Biochar) and T_6 (50 % RDF + 5 t ha^{-1} Biochar + ZMB + Zn) in 2022 had a plant height of 55.9 cm and 56.1 cm. while in 2023 T_4 and T_6 had a plant height of 57.8 cm and 59.0 cm. Including biofertilizers in treatments (T_5, T_6, T_8, and T_9) further augmented plant height. These treatments consistently exhibited higher plant heights compared to treatments without biofertilizer at all growth stages and in both years. For instance, at 90 DAT in 2022, treatment T_9 (100 % RDF + 2.5 t ha^{-1} Biochar + ZMB + Zn) had a plant height of 110.5 cm, while T_4 and T_7 without biofertilizer had plant heights ranging from 101.1 cm to 104.1 cm and 105.9 cm to 107.1 cm respectively for both the years. The integration of biofertilizers further enhances the plant height response, showcasing the potential of combined nutrient management strategies for improved crop growth. Overall, these findings contribute valuable insights for optimizing biochar and fertility management practices to enhance plant height and potentially crop productivity in sustainable agriculture. This result corroborated with findings of Gul et al. (2015), Khedwal et al. (2018), Sharanabasappa and Basavanneppa (2019), Ponmozhi et al. (2019), Singh et al. (2021), Akhtar et al. (2021) and Khan et al. (2021).

The data regarding the no. of tillers is presented in Table 2 and Fig. 2 at different growth stages, 30 DAT, 60 DAT, 90 DAT, and at harvest stage. The data demonstrate the positive influence of biochar and fertility levels on the tillers (m^2) throughout the crop's growth stages in both years. Treatment incorporating biochar (T_4-T_9) consistently exhibited higher number of tillers compared to the control treatment (T_1). In control at 30 DAT in 2022 and 2023 had the no. of tillers (m^2) of 115 (m^2) and 117 (m^2) respectively, while treatment T_2 (100% RDF100:60:40, N P_2O_5, K_2O) had the no. of tillers (m^2) of 136 (m^2) and 138 (m^2) for both years and T_3 (50 % RDF) had the no. of tillers (m^2) 132 (m^2) and 135 (m^2) for both the years respectively. However, the maximum no of tillers (m^2) was recorded with the application of T_9 with values 152 (m^2) and 155 (m^2) respectively for both the years. This trend was evident throughout all growth stages in both year of experimentation, highlighting the positive impact of biochar on no of tillers (m^2). In T_7 (100

% RDF + 2.5 t ha^{-1} Biochar) and T_9 (100 % RDF + 2.5 t ha^{-1} Biochar + ZMB + Zn) at 60 DAT in 2022 had the no. of tillers (m^2) with values of 295 (m^2) and 328 (m^2) respectively, and in 2023 T_7 and T_9 had the no. of tillers (m^2) with values of 304 (m^2) and 338 (m^2) respectively. While T_4 (50 % RDF + 5 t ha^{-1} Biochar) and T6 (50 % RDF + 5 t ha^{-1} Biochar + ZMB + Zn) in 2022 had the no. of tillers (m^2) with values of 265 (m^2) and 277 (m^2). But in 2023 T_4 and T_6 had the no. of tillers (m^2) with values of 274 (m^2) and 288 (m^2). The inclusion of biofertilizer in treatments (T5, T6, T8, and T9) further augmented the no. of tillers. These treatments consistently exhibited higher he no of tillers compared to treatments without biofertilizer at all growth stages and in both years. For instance, at 90 DAS in 2022, treatment T_9 (100 % RDF + 2.5 t ha^{-1} Biochar + ZMB + Zn) had the no. of tillers with the values of 308 (m^2), while treatments without biofertilizer had number of tillers ranging from 246 (m^2) to 274 (m^2) respectively for both years. The same trends were also found at harvest stage of the crop during both the year of experimentation. Overall, the results demonstrate that the application of biochar and the inclusion of biofertilizer positively influence the no. of tillers at different growth stages of the crop. The integration of biofertilizer further enhances the no. of tillers response, showcasing the potential of combined nutrient management strategies for improved crop growth. Overall, these findings contribute valuable insights for optimizing biochar and fertility management practices to enhance the no. of tillers and potentially crop productivity in sustainable agriculture. This result corroborated with finding of Oladele et al. (2019), Khan et al. (2021), Gowthami et al. (2022) and Shukla et al. (2023).

The data regarding root length presented in Table 3 and Fig. 3 at different growth stages, 30 DAT, 60 DAT, 90 DAT, and at harvest stage. The data demonstrate the positive influence of biochar and fertility levels on root length throughout the crop's growth stages in both years. The application of biochar and biofertilizer an increased in root length was observed. Treatment incorporating biochar (T_4-T_9) consistently exhibited higher plant heights compared to the control treatment (T_1). In control at 30 DAT in 2022 and 2023 had a root length of 7.0 cm and 7.3 cm respectively, while treatment T_2 (100% RDF100:60:40, N P_2O_5, K_2O) had a root length of 10.5 cm and 10.7 cm for both years and T_3 (50 % RDF) had a root length 10.1 cm and 10.5 cm for both the years respectively. However, the maximum root length was recorded with the application of T_9 (12.4 cm and 12.9 cm) for both the years. This trend was evident throughout all growth stages in both year of experimentation, highlighting the positive impact of biochar on root length. In T_7 (100 % RDF + 2.5 t ha^{-1} Biochar) and T9 (100 % RDF + 2.5 t/ha-1 Biochar + ZMB + Zn) at 60 DAT in 2022 had a root length of 33.7 cm and 35.7 cm respectively, and in 2023 T_7 and T_9 had a root length of 34.8 and 36.8 respectively. while T_4 (50 % RDF + 5 t ha^{-1} Biochar) and T_6 (50 % RDF + 5 t ha^{-1} Biochar + ZMB + Zn) in 2022 had a root length of 28.7 cm and 32.8 cm. while in 2023 T_4 and T_6 had a root length of 30.4 cm and 34.2 cm. The inclusion of Biofertilizer in treatments (T_5, T_6, T_8, and T_9) further augmented root length. These treatments consistently exhibited higher root length compared to treatments without biofertilizer at all growth stages and in both years. For instance, at 90 DAS in 2022 and 2023, treatment T9 (100 % RDF + 2.5 t ha^{-1} Biochar + ZMB + Zn) had a root length of 33.7 cm and 34.5 respectively, while treatments without biofertilizer had root length ranging from 27.9 cm to 28.1 cm and 31.9 cm to 32.7 cm respectively for both the years. The same trends were also found at harvest stage of the crop during both the year of experimentation. Overall, the results demonstrate that the application of biochar and the inclusion of biofertilizer positively influence root length at different growth stages of the crop. Moreover, the dose-response relationship indicates that higher doses of biochar lead to greater root length. The integration of biofertilizer further enhances the root length response, showcasing the potential of combined nutrient management strategies for improved crop growth. Overall, these findings contribute valuable insights for optimizing biochar and fertility management practices to enhance root length and potentially crop productivity in sustainable agriculture. This result corroborated with finding of Kamara et al. (2015), Thavanesanand Seran (2018), Sial et al. (2019), Oladele et al. (2019).

The data regarding root volume presented in Table 4 and Fig. 4 at different growth stages, 30 DAT, 60 DAT, 90 DAT, and at harvest stage. The data demonstrate the positive influence of biochar and fertility levels on root volume throughout the crop's growth stages in both years. The application of biochar and biofertilizer an increased in root volume was observed. Treatment incorporating biochar (T_4-T_9) consistently exhibited higher root volume compared to the control treatment (T_1).In control at 30 DAT in 2022 and 2023 had a root volume of 18.8 cm and 20.8 cm respectively, while T_3 (50 % RDF) had a root volume of 21.0 cm and 23.4 cm for both the years respectively. However, the maximum root volume was recorded with the application of T_9 (23.6 cm in 2022 and T8 (25.7 cm) in 2023. This trend was evident throughout all growth stages in both year of experimentation, highlighting the positive impact of biochar on root volume. In T_7 (100 % RDF + 2.5 t ha^{-1} Biochar) and T_9 (100 % RDF + 2.5 t ha^{-1} Biochar + ZMB + Zn) at 60 DAT in 2022 had a root volume of 39.0 cm and 40.8 cm respectively, but in 2023 T_7 and T_9 had a root volume of 41.3 cm and 42.9 cm respectively. while T_4 (50 % RDF + 5 t ha^{-1} Biochar) and T_6 (50 % RDF + 5 t ha^{-1} Biochar + ZMB + Zn) in 2022 had a root volume of 36.8 cm and 38.5 cm. while in 2023 T_4 and T_6 had a root volume of 38.4 cm and 40.2 cm. The inclusion of biofertilizer in treatments (T_5, T_6, T_8, and T_9) further augmented root volume.

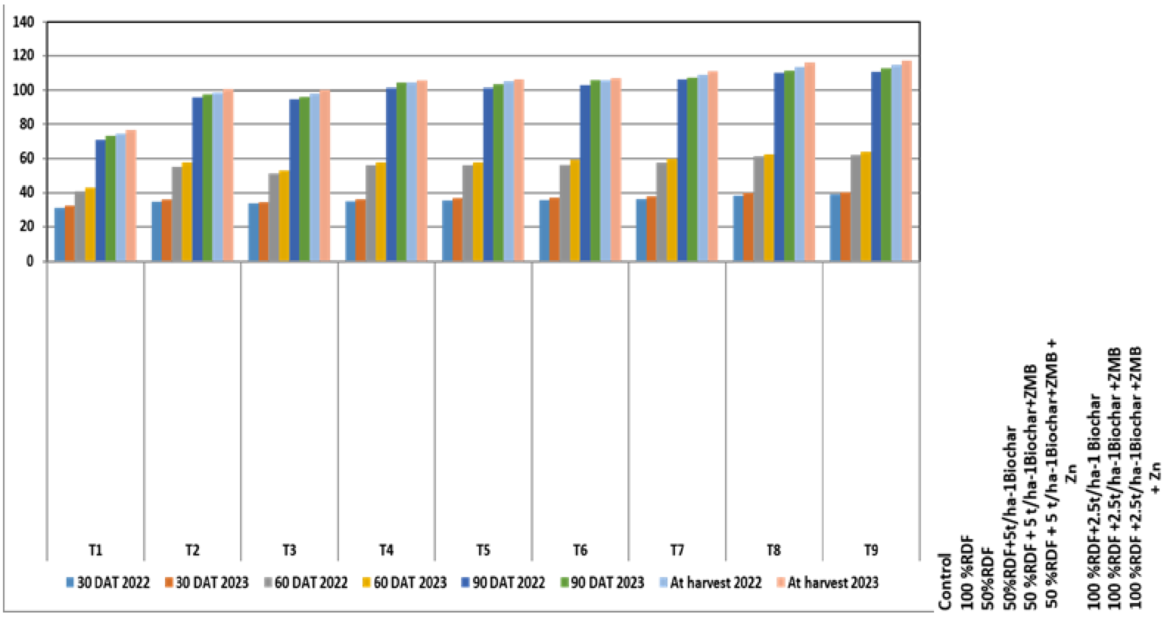

Fig. 1. Effect of biochar and fertility levels on plant height (cm) at different intervals of rice

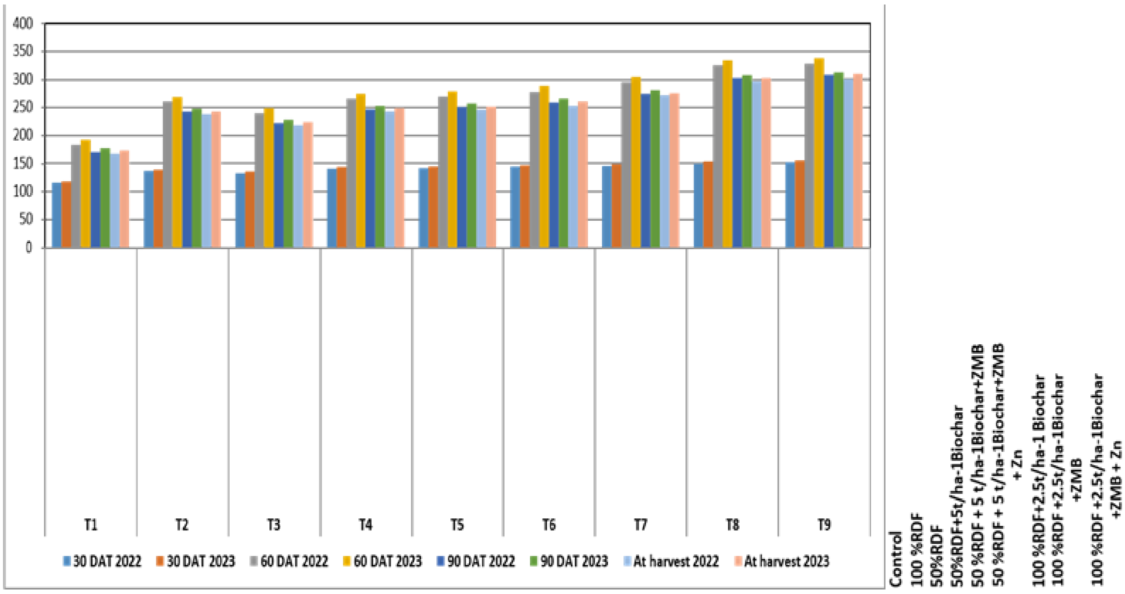

Fig. 2. Effect of biochar and fertility levels on no. of tillers (m^2) at different intervals of rice.

Table 1. Effect of biochar and fertility levels on plant height (cm) at different intervals of rice

Symbol	**Treatments**	**Plant height (cm)**							
		30 DAT		**60 DAT**		**90 DAT**		**At harvest**	
		2022	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
T1	Control	30.9	32.2	40.6	42.9	70.8	72.9	74.2	76.4
T2	100 % RDF	34.5	35.9	54.9	57.8	95.5	97.4	98.4	100.5
T3	50% RDF	33.5	34.3	51.0	52.9	94.5	95.8	97.8	99.9
T4	50% RDF + 5 t ha^{-1}Biochar	34.8	36.0	55.9	57.8	101.1	104.1	104.1	105.3
T5	50 % RDF + 5 t ha^{-1} Biochar + ZMB	35.2	36.7	55.9	57.8	101.1	103.1	104.8	106.0
T6	50 % RDF + 5 t ha^{-1} Biochar + ZMB + Zn	35.5	37.0	56.1	59.0	102.5	105.6	105.5	106.7
T7	100 % RDF + 2.5 t ha^{-1} Biochar	36.1	37.7	57.5	59.5	105.9	107.1	108.6	110.9
T8	100 % RDF + 2.5 t ha^{-1} Biochar + ZMB	38.2	39.8	60.9	62.1	109.9	111.2	113.3	115.7
T9	100 % RDF + 2.5 t ha^{-1} Biochar + ZMB + Zn	38.9	40.1	61.8	63.8	110.5	112.7	114.6	116.8
	SE m±	1.14	1.18	1.78	1.84	3.20	3.26	3.31	3.37
	CD (P= 0.05)	3.33	3.47	5.20	5.39	9.37	9.54	9.68	9.85

Table 2. Effect of biochar and fertility levels on no. of tillers (m^{2}) at different intervals of rice

Symbol	**Treatments**	**Number of tillers (m^{2})**							
		30 DAT		**60 DAT**		**90 DAT**		**At harvest**	
		2022	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
T1	Control	115	117	183	192	170	177	167	173
T2	100 % RDF	136	138	260	268	242	247	237	242
T3	50% RDF	132	135	239	248	222	228	218	224
T4	50% RDF + 5 t ha^{-1}Biochar	140	143	265	274	246	252	242	248
T5	50 % RDF + 5 t ha^{-1} Biochar + ZMB	141	144	269	278	250	256	245	251
T6	50 % RDF + 5 t ha^{-1} Biochar + ZMB + Zn	144	146	277	288	258	265	252	260
T7	100 % RDF + 2.5 t ha^{-1} Biochar	145	148	295	304	274	280	271	275
T8	100 % RDF + 2.5 t ha^{-1} Biochar + ZMB	149	153	325	334	302	307	296	302
T9	100 % RDF + 2.5 t ha^{-1} Biochar + ZMB + Zn	152	155	328	338	308	312	300	310
	SE m±	4.50	4.59	8.72	9.01	8.10	8.29	7.95	8.14
	CD (P= 0.05)	13.16	13.44	25.51	26.35	23.71	24.25	23.27	23.80

These treatments consistently exhibited higher root volume compared to treatments without biofertilizer at all growth stages and in both years. For instance, at 90 DAT in 2022 and 2023 treatment T_9 (100 % RDF + 2.5 t ha^{-1} Biochar + ZMB + Zn) had a root volume of 50.7 cm and 52.4 respectively, while treatments without biofertilizer had root volume ranging from 44.8 cm to 47.2 cm and 46.3 cm to 49.7 cm respectively for both the years. The same trends were also found at the harvest stage of the crop during both years of experimentation. Overall, the results demonstrate that the application of biochar and the inclusion of biofertilizer positively influence root volume at different growth stages of the crop. Moreover, the dose-response relationship indicates that higher doses of biochar lead to greater root volume. The integration of biofertilizer further enhances the root volume response, showcasing the potential of combined nutrient management strategies for improved crop growth. Overall, these findings contribute valuable insights for optimizing biochar and fertility management practices to enhance root volume and potentially crop productivity in sustainable agriculture. This result corroborated with finding of Kamara et al. (2015), Wang et al. (2018), Thavanesan and Seran (2018), Sial et al. (2019), Oladele et al. (2019) and Liu et al. (2021).

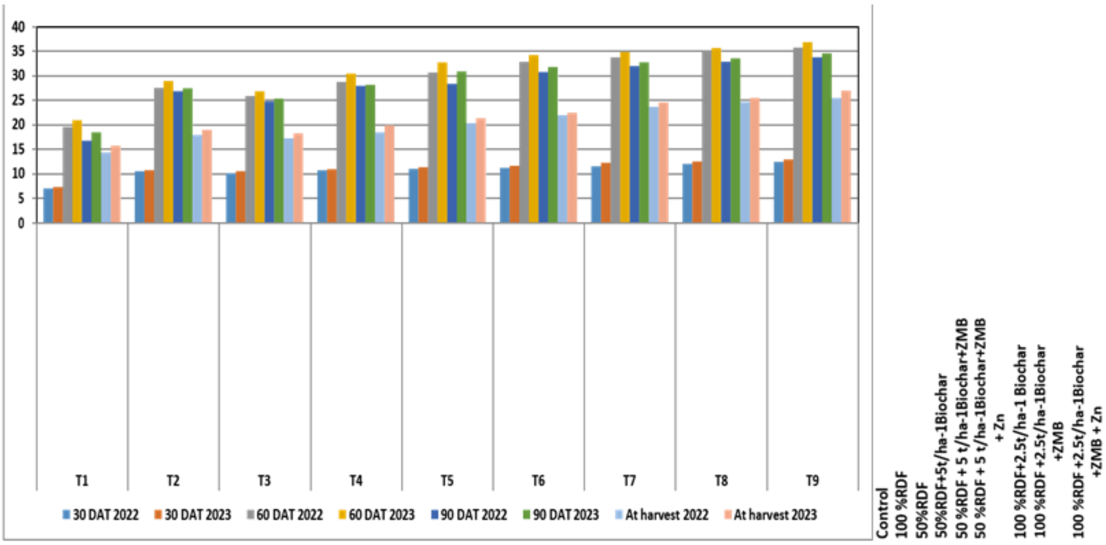

Fig. 3. Effect of biochar and fertility levels on root length (cm) at different intervals of rice

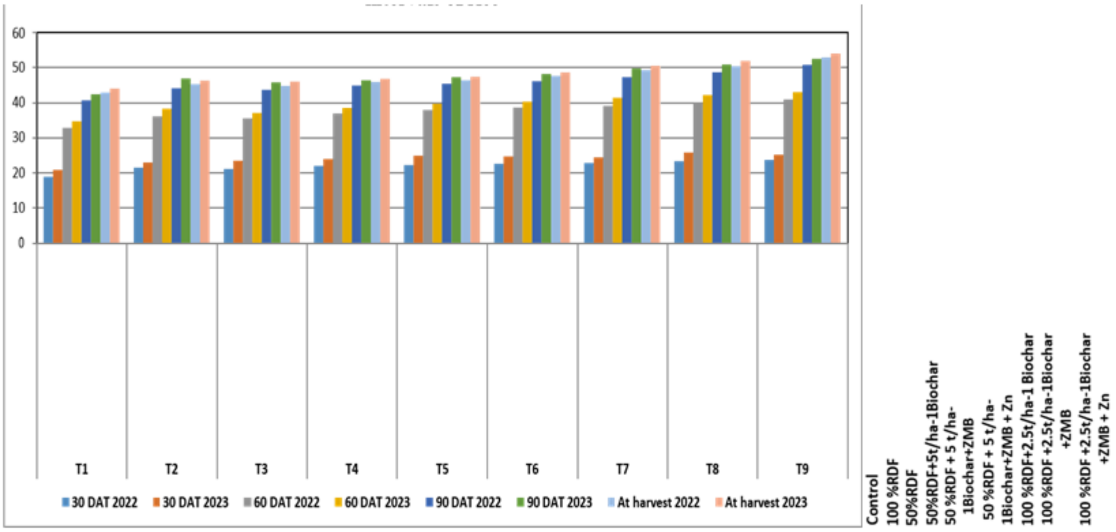

Fig. 4. Effect of biochar and fertility levels on root volume at different intervals of rice

Table 3. Effect of biochar and fertility levels on root length (cm) at different intervals of rice

Symbol	**Treatments**	**Root length (cm)**							
		30 DAT		**60 DAT**		**90 DAT**		**At harvest**	
		2022	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
T1	Control	7.0	7.3	19.5	20.9	16.7	18.4	14.3	15.7
T2	100 % RDF	10.5	10.7	27.5	28.9	26.8	27.4	17.9	18.9
T3	50% RDF	10.1	10.5	25.8	26.8	24.7	25.3	17.2	18.2
T4	50% RDF + 5 t ha^{-1}Biochar	10.7	10.9	28.7	30.4	27.9	28.1	18.4	19.8
T5	50 % RDF + 5 t ha^{-1} Biochar + ZMB	11.0	11.3	30.6	32.7	28.3	30.8	20.3	21.3
T6	50 % RDF + 5 t ha^{-1} Biochar + ZMB + Zn	11.2	11.6	32.8	34.2	30.7	31.7	21.9	22.4
T7	100 % RDF + 2.5 t ha^{-1} Biochar	11.5	12.2	33.7	34.8	31.9	32.7	23.6	24.5
T8	100 % RDF + 2.5 t ha^{-1} Biochar + ZMB	12.0	12.5	34.8	35.6	32.8	33.5	24.6	25.4
T9	100 % RDF + 2.5 t ha^{-1} Biochar + ZMB + Zn	12.4	12.9	35.7	36.8	33.7	34.5	25.4	26.9
	SEm±	0.35	0.36	0.96	1.01	0.90	0.95	0.65	0.69
	CD (P= 0.05)	1.01	1.05	2.82	2.96	2.64	2.77	1.91	2.01

Table 4. Effect of biochar and fertility levels on root volume at different intervals of rice

Symbol	**Treatments**	**Root Volume**							
		30 DAT		**60 DAT**		**90 DAT**		**At harvest**	
		2022	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
T1	Control	18.8	20.8	32.7	34.6	40.6	42.3	42.8	43.9
T2	100 % RDF	21.4	22.9	36.0	38.2	44.0	46.8	45.2	46.2
T3	50% RDF	21.0	23.4	35.4	37.0	43.6	45.7	44.7	45.9
T4	50% RDF + 5 t ha^{-1}Biochar	21.9	23.9	36.8	38.4	44.8	46.3	45.8	46.7
T5	50 % RDF + 5 t ha^{-1} Biochar + ZMB	22.1	24.8	37.8	39.6	45.3	47.2	46.3	47.3
T6	50 % RDF + 5 t ha^{-1} Biochar + ZMB + Zn	22.5	24.6	38.5	40.2	46.0	48.1	47.5	48.5
T7	100 % RDF + 2.5 t ha^{-1} Biochar	22.7	24.3	39.0	41.3	47.2	49.7	49.2	50.4
T8	100 % RDF + 2.5 t ha^{-1} Biochar + ZMB	23.2	25.7	39.7	42.1	48.6	50.8	50.3	51.8
T9	100 % RDF + 2.5 t ha^{-1} Biochar + ZMB + Zn	23.6	25.1	40.8	42.9	50.7	52.4	52.8	53.9
	SEm±	0.74	0.81	1.26	1.33	1.54	1.61	1.60	1.63
	CD (P= 0.05)	2.14	2.34	3.67	3.86	4.49	4.68	4.64	4.75

Table 5. Effect of biochar and fertility levels on leaf area index at different intervals of rice

Symbol	Treatments	Leaf area index (LAI)					
		30 DAT		60 DAT		90 DAT	
		2022	2023	2022	2023	2022	2023
T1	Control	2.12	2.31	4.46	4.77	4.40	4.66
T2	100 % RDF	2.39	2.61	5.37	5.75	5.24	5.55
T3	50% RDF	2.37	2.58	5.33	5.70	5.11	5.42
T4	50% RDF + 5 t ha^{-1}Biochar	2.42	2.64	5.96	6.38	5.85	6.20
T5	50 % RDF + 5 t ha^{-1} Biochar + ZMB	2.44	2.66	6.25	6.69	6.19	6.56
T6	50 % RDF + 5 t ha^{-1} Biochar + ZMB + Zn	2.46	2.68	6.32	6.76	6.23	6.60
T7	100 % RDF + 2.5 t ha^{-1} Biochar	2.48	2.70	6.37	6.81	6.25	6.63
T8	100 % RDF + 2.5 t ha^{-1} Biochar + ZMB	2.58	2.81	6.98	7.47	6.88	7.29
T9	100 % RDF + 2.5 t ha^{-1} Biochar + ZMB + Zn	2.60	2.84	7.02	7.52	6.94	7.33
	SE m±	0.08	0.09	0.19	0.21	0.19	0.20
	CD (P= 0.05)	0.23	0.25	0.57	0.61	0.56	0.59

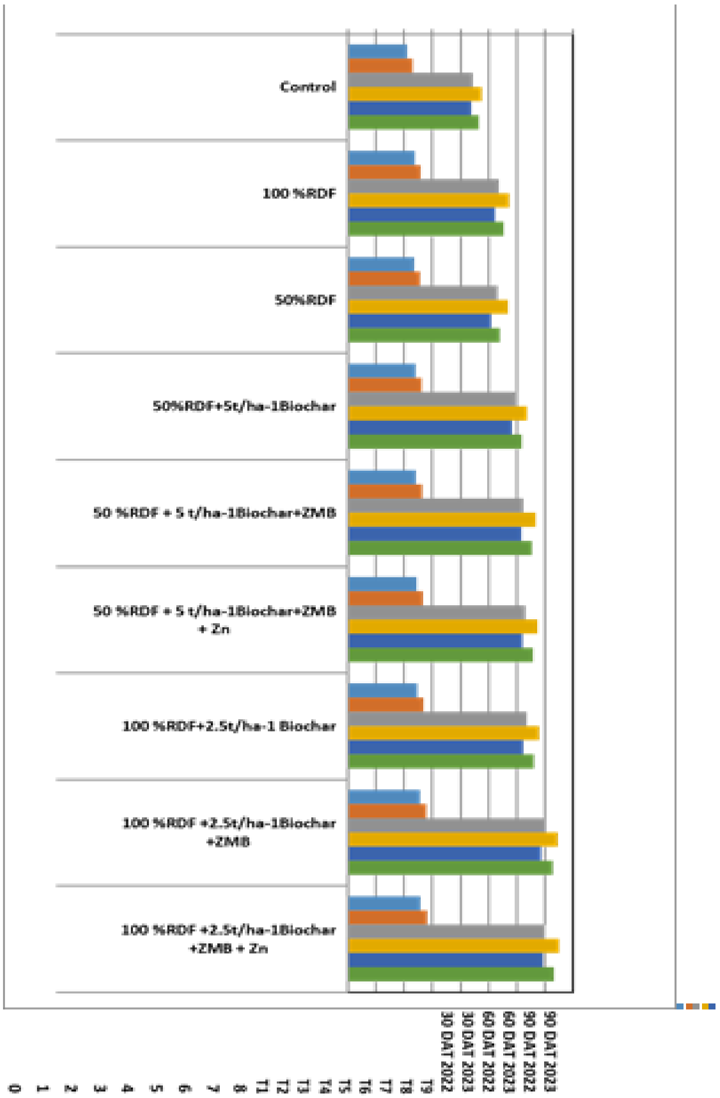

Fig. 5. Effect of biochar and fertility levels on leaf area index at different intervals of rice.

The data regarding Leaf area index presented in Table 5 and Fig. 5 at different growth stages, 30 DAT, 60 DAT and 90 DAT. The data demonstrate the positive influence of biochar and fertility levels on Leaf area index throughout the crop's growth stages in both years. The application of biochar and biofertilizer an increased in Leaf area index was observed. Treatment incorporating biochar (T_4-T_9) consistently exhibited higher Leaf area index compared to the control treatment (T_1). In control at 30 DAT in 2022 and 2023 had a Leaf area index of 2.12and 2.31 respectively, while treatment T_2 (100% RDF 100:60:40, N P2O5, K2O) had a Leaf area index of 2.39 and 2.61 for both years and T_3 (50 % RDF) had a Leaf area index 2.37 and 2.58 for both the years respectively. However, the maximum Leaf area index was recorded with the application of T_9 (2.60and 2.84) for both the years respectively. This trend was evident throughout all growth stages in both year of experimentation, highlighting the positive impact of biochar on Leaf area index. In T_7 (100 % RDF + 2.5 t ha^{-1} Biochar) and T_9 (100 % RDF + 2.5 t ha^{-1} Biochar + ZMB + Zn) at 60 DAT in 2022 had a Leaf area index of 6.37and 7.02 respectively, but in 2023 T_7 and T_9 had a Leaf area index of 6.81 and 7.52 respectively. While T_4 (50 % RDF + 5 t ha^{-1} Biochar) and T_6 (50 % RDF + 5 t ha^{-1} Biochar + ZMB + Zn) in 2022 had a Leaf area index of 5.96 and 6.32. But in 2023 T_4 and T_6 had a Leaf area index of 6.38 and 6.76. The inclusion of biofertilizer in treatments (T_5, T_6, T_8, and T_9)

further augmented Leaf area index. These treatments consistently exhibited higher Leaf area index compared to treatments without biofertilizer at all growth stages and in both years. For instance, at 90 DAT in 2022 and 2023, treatment T_9 (100 % RDF + 2.5 t ha^{-1} Biochar + ZMB + Zn) had a Leaf area index of 6.94 and 7.33 respectively, while treatments without biofertilizer (T_4 to T_7) had Leaf area index ranging from (5.85 to 6.25) and (6.20 to 6.63) respectively for both the years. Overall, the results demonstrate that the application of biochar and the inclusion of biofertilizer positively influence Leaf area index at different growth stages of the crop. Moreover, the dose-response relationship indicates that higher doses of biochar lead to greater Leaf area index. The integration of biofertilizer further enhances the Leaf area index response, showcasing the potential of combined nutrient management strategies for improved crop growth. Overall, these findings contribute valuable insights for optimizing biochar and fertility management practices to enhance Leaf area index and potentially crop productivity in sustainable agriculture. This result corroborated with finding of Gul et al. (2015), Khedwal et al. (2018) Sharanabasappa and Basavanneppa (2019), Singh et al. (2021), Khan et al. (2021) and Krishna et al. (2024).

The data regarding dry matter accumulation presented in Table 6 and Fig. 6 at different growth stages, 30 DAT, 60 DAT, 90 DAT and harvest stage. The application of biochar and biofertilizer an increased in dry matter accumulation was observed. Treatment incorporating biochar (T_4-T_9) consistently exhibited higher dry matter accumulation index compared to the control treatment (T_1). In control at 30 DAT in 2022 and 2023 had the dry matter accumulation of 125.3 (g m^{-2}) and 129.1 (g m^{-2}), while treatment T_2 (100% RDF100:60:40, N P_2O_5, K_2O) had the dry matter accumulation of 140.5 (g m^{-2}) and 144.7(g m^{-2}). However, the maximum dry matter accumulation was recorded with the application of T9. This trend was evident throughout all growth stages in both year of experimentation, highlighting the positive impact of biochar on dry matter accumulation. In T_7 (100 % RDF + 2.5 t ha^{-1} Biochar) and T_9 (100 % RDF + 2.5 t ha^{-1} Biochar + ZMB + Zn) at 60 DAT in 2022 had the dry matter accumulation of 531.9 (g m^{-2}) and 570.4 (g m^{-2}) respectively, But in 2023 T_7 and T_9 had the dry matter accumulation of 542.5(g m^{-2}) and 492.7(g m^{-2}) respectively, While T_4 (50 % RDF + 5 t ha^{-1} Biochar) and T6 (50 % RDF + 5 t ha^{-1} Biochar + ZMB + Zn) in 2022 had the dry matter accumulation of 522.1(g m^{-2}) and 528.8 (g m^{-2}) respectively. But in 2023 T_4 and T_6 had the dry matter accumulation of 532.5 (g m^{-2}) and 539.4 (g m^{-2}) respectively. The inclusion of biofertilizer in treatments (T_5, T_6, T_8, and T_9) further augmented dry matter accumulation. These treatments consistently exhibited higher dry matter accumulation compared to treatments without biofertilizer at all growth stages and in both years. For instance, at 90 DAT in 2022 and 2023, treatment T9 (100 % RDF + 2.5 t ha^{-1} Biochar + ZMB + Zn) had a dry matter accumulation of 772.4 (g m^{-2}) and 772.4 (g m^{-2}) respectively, while treatments without biofertilizer (T_4 to T_7) had dry matter accumulation ranging from 698.5 (g m^{-2}) to 711.6 (g m^{-2}) and 712.5 (g m^{-2}) to 725.8 (g m^{-2}) respectively for both the years. The same trends were also found at the harvest stage of the crop during both years of experimentation. Overall, the results demonstrate that the application of biochar and the inclusion of biofertilizer positively influence dry matter accumulation at different growth stages of the crop. The integration of biofertilizer further enhances the dry matter accumulation response, showcasing the potential of combined nutrient management strategies for improved crop growth. Overall, these findings contribute valuable insights for optimizing biochar and fertility management practices to enhance dry matter accumulation and potentially crop productivity in sustainable agriculture. These results corroborated with finding of Gul et al. (2015), Roa et al. (2016), Koca et al. (2016), Khedwal et al. (2018), Islam et al. (2018), Ponmozhi et al. (2019), Kumar et al. (2020), Singh et al. (2021), Khan et al. (2022) and Cao et al. (2024).

Table 7 and Fig. 7 presents the crop growth rate (CGR) in grams per square meter per day (gm^{-2} day^{-1}) at different growth stages, 30-60 DAT, 60-90 DAT, and 90 DAT to at harvest, for the years 2022 and 2023. The study includes nine treatments, each representing different combinations of biochar, fertility levels, and biofertilizer, along with the corresponding standard error of the mean (SE m±) and critical difference at the 5% level of significance (CD). The data demonstrate the impact of biochar and fertility levels on the crop growth rate throughout the different growth stages in both years. In the control treatment (T_1), without any biochar or biofertilizer, the crop growth rate ranged from 6.78 to 7.39 gm^{-2} day^{-1} in 2022 and from 6.87 to 7.19 gm^{-2} day^{-1} in 2023. However, treatments with biochar and/or biofertilizer consistently exhibited higher crop growth rates compared to the control. Treatments with biochar (T_4-T_9) consistently displayed higher crop growth rates compared to the control treatment (T_1). For instance, at 30-60 DAT in 2022, the control treatment (T_1) had a crop growth rate of 6.78 gm^{-2} day^{-1}, and treatment T_2 (100% RDF) had a crop growth rate of 10.43 gm^{-2} day^{-1}. While treatment T_9 (100% RDF 100:60:40, N P_2O_5, K_2O with 2.5 t ha^{-1} biochar and ZMB biofertilizer +Zn) had a crop growth rate of 13.44 gm-2 day^{-1}. This trend was observed across all growth stages and in both years, indicating the positive impact of biochar on the crop growth rate. T_7 (100 % RDF + 2.5 t ha^{-1} Biochar) and T_9 (100 % RDF + 2.5 t ha^{-1} Biochar + ZMB + Zn) at 60-90 DAT in 2022 had a crop growth rate of 5.99(g m^{-2}) and 6.73(g m^{-2}) respectively, But in 2023 T_7 and T_9 had a crop growth rate of 6.11 (g m^{-2}) and 6.42 (g m^{-2}) respectively, While T_4 (50 % RDF + 5 t ha^{-1} Biochar) and T_6 (50 % RDF + 5 t ha^{-1} Biochar + ZMB + Zn) in 2022 had a crop growth rate of 5.88 (g m^{-2}) and 5.99 (g m^{-2}) respectively. But in 2023 T_4 and T_6 had a crop growth rate of 6.00(g m^{-2}) and 6.11 (g m^{-2}) respectively, the same trends were also found at 90- at the harvest stage of the crop during both the year of experimentation. The inclusion of biofertilizers in some treatments (T_5, T_6, T_8, and T_9) further enhanced the crop growth rate. These treatments consistently exhibited higher crop growth rates compared to treatments without biofertilizer at all growth stages and in both years. The results indicate the significant influence of biochar and the integration of biofertilizers on the crop growth rate at different growth stages. The consistent increase in crop growth rate with the application of biochar suggests its positive effect on enhancing plant growth and productivity. Moreover, the observed dose-response relationship highlights the importance of optimizing biochar doses to achieve maximum crop growth rates. Additionally, the inclusion of biofertilizers in some treatments further enhances the crop growth rate, indicating its role in promoting nutrient uptake and overall plant growth. The combination of biochar and biofertilizer shows promising synergistic effects on the crop's growth, which can lead to improved crop performance and yield potential. Overall, the findings from this study provide valuable insights into the benefits of using biochar and biofertilizer as integrated soil management practices to enhance crop growth rates and potentially optimize agricultural productivity. Further investigation is warranted to better understand the underlying mechanisms driving these responses and to explore the long-term implications of these practices on overall crop performance and sustainable agriculture. Finding of the investigation may be confirmed by the earlier research workers Prasad et al. (2017), Khedwal et al. (2018) Raza et al. (2023) and Jinjala et al. (2024).

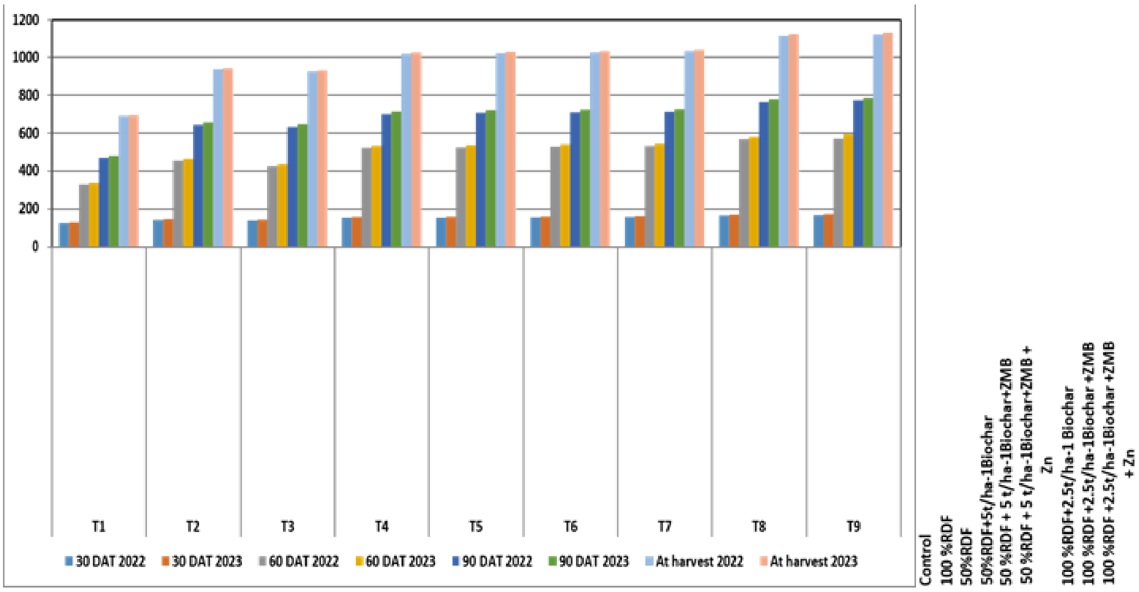

Fig. 6. Effect of Biochar and fertility levels on dry matter accumulation (g m^{-2}) at different intervals of rice

Table 6. Effect of Biochar and fertility levels on dry matter accumulation (g m^{-2}) at different intervals of rice.

Symbol	Treatments	Dry matter accumulation (g m^{-2})							
		30 DAT		60 DAT		90 DAT		At harvest	
		2022	2023	2022	2023	2022	2023	2022	2023
T1	Control	125.3	129.1	328.7	335.3	468.6	478.0	690.2	693.7
T2	100 % RDF	140.5	144.7	453.4	462.5	642.0	654.8	936.8	942.3
T3	50% RDF	137.1	141.2	426.5	435.0	632.6	645.3	925.3	930.5
T4	50% RDF + 5 t ha^{-1}Biochar	152.1	156.7	522.1	532.5	698.5	712.5	1017.7	1025.2
T5	50 % RDF + 5 t ha^{-1} Biochar + ZMB	152.5	157.1	524.1	534.6	705.7	719.8	1021.0	1028.5
T6	50 % RDF + 5 t ha^{-1} Biochar + ZMB + Zn	154.1	158.7	528.8	539.4	708.6	722.8	1025.2	1032.8
T7	100 % RDF + 2.5 t ha^{-1} Biochar	156.4	161.1	531.9	542.5	711.6	725.8	1032.3	1040.1
T8	100 % RDF + 2.5 t ha^{-1} Biochar + ZMB	164.7	169.6	568.7	580.1	762.4	777.6	1111.3	1121.0
T9	100 % RDF + 2.5 t ha^{-1} Biochar + ZMB + Zn	167.3	172.8	570.4	592.7	772.4	785.4	1118.5	1128.4
	SE m±	4.84	4.99	16.08	16.40	21.96	22.40	31.93	32.16
	CD (P= 0.05)	14.16	14.59	47.03	47.97	64.23	65.52	93.41	94.08

Table 7. Effect of Biochar and fertility levels on crop growth rate (g/m2/day) at different intervals of rice.

Symbol	Treatments	Crop growth rate (g/m^2/day)					
		30-60 DAT		60-90 DAT		90- at harvest	
		2022	2023	2022	2023	2022	2023
T1	Control	6.78	6.87	4.66	4.76	7.39	7.19
T2	100 % RDF	10.43	10.59	6.29	6.41	9.83	9.58
T3	50% RDF	9.65	9.79	6.87	7.01	9.76	9.51
T4	50% RDF + 5 t ha^{-1}Biochar	12.33	12.53	5.88	6.00	10.64	10.42
T5	50 % RDF + 5 t ha^{-1} Biochar + ZMB	12.39	12.58	6.05	6.17	10.51	10.29
T6	50 % RDF + 5 t ha^{-1} Biochar + ZMB + Zn	12.49	12.69	5.99	6.11	10.55	10.33
T7	100 % RDF + 2.5 t ha^{-1} Biochar	12.52	12.71	5.99	6.11	10.69	10.48
T8	100 % RDF + 2.5 t ha^{-1} Biochar + ZMB	13.47	13.68	6.46	6.58	11.63	11.45
T9	100 % RDF + 2.5 t ha^{-1} Biochar + ZMB + Zn	13.44	14.00	6.73	6.42	11.54	11.43
	SE m±	0.38	0.40	0.20	0.21	0.34	0.33
	CD (P= 0.05)	1.10	1.21	0.58	0.62	1.01	0.97

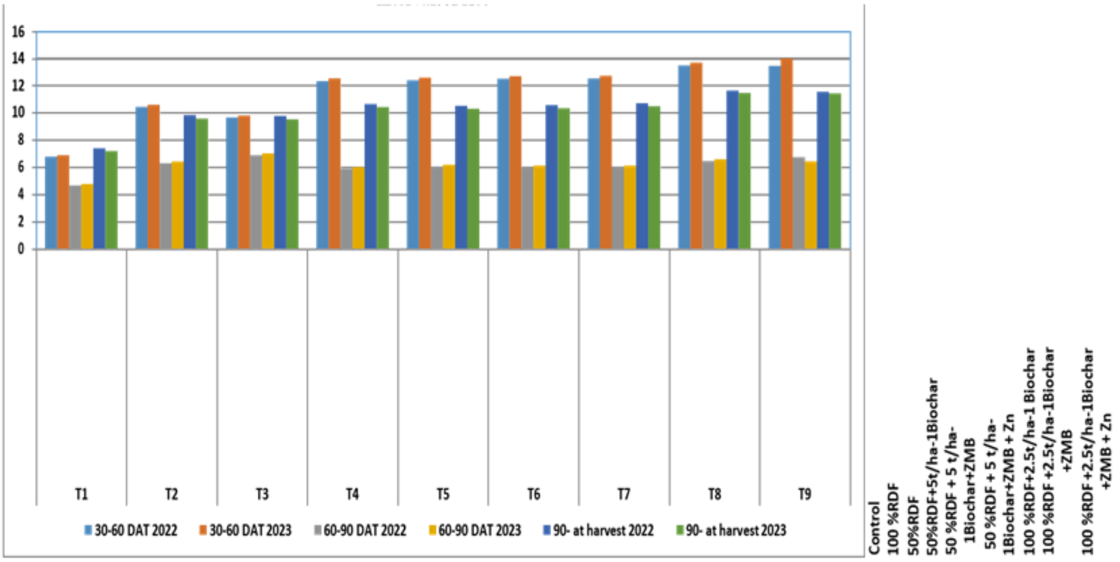

Fig. 7. Effect of Biochar and fertility levels on crop growth rate (g/m^2/day) at different intervals of rice

4. CONCLUSION

In conclusion, the study demonstrated the significant influence of biochar and varying fertility levels on rice growth and yield parameters across 2022 and 2023. Compared to the control, Biochar consistently enhanced plant height, root length, tiller density, leaf area index, dry matter accumulation, and crop growth rate. Treatments integrating biochar with 100% recommended fertilizer dose and biofertilizer, particularly T_9 (100% RDF + 2.5 t ha^{-1}Biochar + ZMB + Zn), consistently outperformed other treatments across all parameters measured. This treatment promoted superior growth and yield of crops. Therefore, T_9 emerges as the optimal treatment choice for maximizing rice productivity and sustainability, offering a balanced approach toward achieving higher benefits in rice cultivation practices.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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