

Organic manure and biochar with inorganic fertilizer's effect on growth dynamics and yield performance of rice (*Oryza sativa*)

KAPIL KUMAR YADAV¹, ANIL KUMAR² AND RAVINDRA KUMAR³

C.S. Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh 208 002

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ABSTRACT

The present study was conducted to evaluate the effects of organic manure, inorganic fertilizers, and biochar, individually and in integrated combinations, on growth, yield attributes, and grain yield of rice (*Oryza sativa* L.). The experiment aimed to assess the comparative effectiveness of these soil amendments in enhancing rice productivity and to explore their potential contribution to sustainable nutrient management. Organic inputs, including farmyard manure and biochar, were applied to improve soil physical properties, nutrient availability, and microbial activity, while inorganic fertilizers supplying nitrogen, phosphorus and potassium were used to meet the immediate nutrient requirements of the crop. Field experiments were carried out during a single growing season using different treatment combinations comprising organic manure alone, inorganic fertilizers alone, biochar alone and their various integrated applications. Growth and yield parameters such as plant height, number of tillers, dry matter accumulation, panicle length, number of grains per panicle and grain yield were recorded. The results indicated that integrated application of organic manure and inorganic fertilizers significantly enhanced growth and yield attributes of rice compared to their sole application. Notably the combined use of biochar and farmyard manure exhibited a synergistic effect by improving soil structure, enhancing nutrient retention and increasing grain yield. The findings demonstrate that integrated nutrient management involving organic manures, inorganic fertilizers and biochar can substantially improve rice productivity while promoting soil health, thereby offering a viable and environmentally sustainable alternative to conventional fertilizer based farming systems.

Key words: Biochar, Inorganic fertilizer, Organic manure, Integrated Nutrient Management, Sustainable agriculture

Rice (*Oryza sativa* L.) is a member of the grass family, Gramineae (Poaceae). As one of the three key food crops globally, it constitutes the staple diet for roughly half of the world's populace. Rice has been cultivated in India for a long time (Sangeetha *et al.*, 2020). Rice serves as the principal food crop globally, providing the main dietary staple for roughly four billion individuals approximately half of all people on Earth. Its agricultural activities span about 160 million hectares across different climatic zones, ranging from 44°N in North Korea to 35°S in Australia. Rice is cultivated in regions that vary greatly in elevation, from about 2.7 meters below sea level, such as Kuttanad in

India's Kerala, to altitudes of 2,700 feet ASL in the foothills of the Himalayas. Rice is essential not just for agriculture; it holds a crucial role in the cultural and historical contexts of many Asian countries, as it is deeply intertwined with their traditions and heritage (NRRI-Bulletin, 2020). Application of organic manure has shown positive effects on rice yield by enhancing nutrient availability and promoting microbial activity. The use of organic manure raises the soil's organic matter content, which enhances its ability to retain water and nutrients (Ghorbani *et al.*, 2023). Inorganic fertilizers, including Nitrogen (N), Phosphorus (P), and Potassium (K) varieties, offer nutrients that are immediately accessible to plants. Proper application of inorganic fertilizers has shown significant increases in rice yield, especially when nutrient deficiencies are addressed (Bhatt *et al.*, 2019). Biochar is produced through pyrolysis of waste plant materials. Application of Biochar to rice fields has yielded encouraging results regarding enhancement of soil fertility and enhancing crop productivity (Oladele *et al.*, 2019). Biochar helps in keeping nutrients in the soil and lowering nutrient leaching, which enhances

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¹Corresponding author's Email: kapil12896@gmail.com

¹Ph.D. Research Scholar, Department of Soil Science and Agricultural Chemistry, C.S. Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh 208 002; ^{2,3}Professors, Department of Soil Science and Agricultural Chemistry, C.S. Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh 208 002

nutrient availability for rice plants. Due to its porous structure, biochar promotes helpful microbial activity in the soil, which enhances nutrient cycling and overall soil health. In the view of above facts, the present study entitled “organic manure and biochar with inorganic fertilizer’s effect on growth dynamics and yield performance of rice (*Oryza sativa* L.)”. Impact of biochar on rice quality characteristic is limited, but its positive impact on soil fertility can indirectly contribute to improved grain quality (Hussain *et al.*, 2017).

MATERIALS AND METHODS

This field experiment was conducted at the Agronomy Research Farm in Nawabganj, part of the Department of Soil Science at Chandra Shekhar Azad University of Agriculture & Technology in Kanpur, during the Kharif season of 2023 and 2024. The soil of experimental field is classified within the soil order of Inceptisols. It is sandy loam in texture and neutral to alkaline in soil reaction. The sixteen treatments were used with three replicates and each consisted of a T₁, Control; T₂, 50% RDF; T₃, 75% RDF; T₄, 100% RDF; T₅, 50% RDF + 5.0 tonnes/ha FYM + 5.0 kg Zinc; T₆, 75% RDF + 5.0 tonnes/ha FYM + 5.0 kg Zinc; T₇, 100% RDF + 5.0 tonnes/ha FYM + 5.0 kg Zinc; T₈, 50% RDF + 5.0 tonnes/ha FYM + Biochar; T₉, 75% RDF + 5.0 tonnes/ha FYM + Biochar; T₁₀, 100% RDF + 5.0 tonnes/ha FYM + Biochar; T₁₁, 50% RDF + 5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar; T₁₂, 75% RDF + 5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar; T₁₃, 100% RDF + 5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar; T₁₄, 5.0 tonnes/ha FYM + 5.0 kg Zinc; T₁₅, 5.0 tonnes/ha FYM + Biochar; T₁₆, 5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar, with Rice (27P 37) crop having a plot size 4 × 5 m. Each treatment was replicated three times and organized using a Randomized Block Design (RBD). After thorough field preparation, initial soil samples were collected to analyze the initial soil properties. The available major nutrients in the initial soil sample were analyzed; N, P, K, Zn, OC, pH and EC. The field used for the experiment had a pH of 8.09, EC 0.32 dS/m, CEC (p+)/kg 39.38 and 0.40% organic carbon. The experimental field had a low N status (203 kg/ha), medium available P (12.80 kg/ha), lower available K (195 kg/ha) and Zn (0.63 mg/kg). All treatments, including Biochar and FYM were assigned to the plots at random and uniformly mixed into the soil to a depth of 10 cm 15 days prior to transplanting the rice seedlings, after which submergence occurred. Prior to puddling, one-third of the nitrogen (from urea) was applied as a basal treatment, together with full doses of potash and phosphorus. This was mixed into the soil to a depth of 15 cm. The remaining nitrogen was supplied as a top-dressing in two applications of urea, during the tillering and panicle initiation stages.

The trial utilized the rice variety 27P37, planted with a spacing of 20 × 10 cm. The crop was manually harvested from each plot once the grains had attained physiological maturity. When around 85% of the panicles contained about 85% ripened spikelets and the upper part of the spikelets had changed to a straw colour, harvesting was carried out with serrated-edge sickles. During the harvest, yields of straw and seed were noted. Plant samples were gathered for the chemical analysis of nitrogen, phosphorus, potassium, and zinc in both seed and straw samples. N was assessed by Alkaline Permanganate method (Subbiah and Asija, 1956), for the available P soil samples were taken using 0.5 M NaHCO₃ (pH = 8.5) as per Olsen *et al.* (1954) and the P content in the extracts was measured by vanado - molybdo phosphoric acid yellow colour method Jackson’s method (1973). K that is available was determined by Flame photometer method (Toth and Prince, 1949) and Available Zn was determined by DTPA method (Lindsay and Norvell, 1978).

RESULTS AND DISCUSSION

Crop Growth Characters: The data presented in Tables 1, 2 and 3 clearly demonstrate that crop growth parameters of rice were significantly influenced by different nutrient management treatments. Among all treatments T₁₃ (100% RDF + 5 t ha⁻¹ FYM + 5 kg Zn + biochar) consistently exhibited superior performance across both years of experimentation as well as on a pooled basis. This treatment recorded the maximum plant height (115.32 cm in 2023 and 116.87 cm in 2024, with a pooled mean of 116.09 cm) highest number of tillers (401.13 m⁻² in 2023 and 404.45 m⁻² in 2024 at 90 DAT, pooled mean 402.79 m⁻²), and maximum dry matter accumulation (874.36 g m⁻² in 2023 and 880.03 g m⁻² in 2024, pooled mean 877.19 g m⁻²). The consistent superiority of T₁₃ across years indicates the robustness and stability of integrated nutrient management practices in enhancing rice vegetative growth. The pronounced improvement in plant height and tiller production under T₁₃ can be attributed to enhanced nutrient availability and improved soil physico chemical and biological properties resulting from the combined application of FYM, zinc and biochar. Farm yard manure serves as a slow release source of macro and micro nutrients and stimulates soil microbial activity, thereby improving nutrient mineralization and uptake (Singh *et al.*, 2021). Zinc plays a crucial role in enzymatic activity, auxin synthesis and chlorophyll formation, which collectively promote cell elongation and tiller initiation. Additionally, biochar improves soil structure, cation exchange capacity, moisture retention and nutrient use efficiency, leading to reduced nutrient losses and sustained nutrient availability to the crop (Yadav *et al.*, 2020). The significantly higher dry

Table 1. Effect of organic manure, inorganic fertilizer and biochar on plant height (cm) at various growth stages of rice during 2023 and 2024

Treatment	Plant height (cm)											
	2023		2024		Mean		2023		2024		Mean	
	30 DAT	30 DAT	60 DAT	60 DAT	Mean	90 DAT	90 DAT	Mean	90 DAT	90 DAT	At Harvest	At Harvest
T ₁ , Control	47.90	49.70	48.8	80.74	81.74	81.24	92.92	93.92	93.42	92.96	96.06	94.51
T ₂ , 50% RDF	48.58	50.45	49.51	81.74	82.34	82.04	93.02	94.02	93.52	93.04	97.24	95.14
T ₃ , 75% RDF	50.15	51.15	50.65	82.05	83.15	82.60	93.47	95.47	94.47	93.95	98.05	96
T ₄ , 100% RDF	51.70	52.40	52.05	83.66	83.66	83.66	94.66	96.60	95.63	94.87	99.97	97.42
T ₅ , 50% RDF +5.0 tonnes/ha FYM + 5.0 kg Zinc	52.25	53.25	52.75	84.76	84.76	84.76	96.46	97.46	96.96	97.21	99.21	98.21
T ₆ , 75% RDF +5.0 tonnes/ha FYM + 5.0 kg Zinc	51.81	52.81	52.31	85.00	85.80	85.40	98.93	100.93	99.93	99.01	101.01	100.01
T ₇ , 100% RDF +5.0 tonnes/ha FYM + 5.0 kg Zinc	52.35	53.38	52.86	86.96	87.96	87.46	99.88	103.88	101.88	101.00	104.00	102.5
T ₈ , 50% RDF +5.0 tonnes/ha FYM + Biochar	53.50	54.56	54.03	88.06	88.56	88.31	100.43	105.43	102.93	103.51	106.51	105.01
T ₉ , 75% RDF +5.0 tonnes/ha FYM + Biochar	54.05	54.65	54.35	91.89	91.69	91.79	101.13	107.13	104.13	105.44	109.14	107.29
T ₁₀ , 100% RDF +5.0 tonnes/ha FYM + Biochar	55.62	56.84	56.23	93.68	94.66	94.17	102.64	109.94	106.29	107.83	111.33	109.58
T ₁₁ , 50% RDF +5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar	56.01	57.31	56.66	95.98	95.00	95.49	103.11	110.91	107.01	109.37	112.95	111.16
T ₁₂ , 75% RDF +5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar	55.62	57.62	56.62	97.68	97.89	97.78	104.21	112.21	108.21	112.34	114.74	113.54
T ₁₃ , 100% RDF +5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar	57.35	58.27	57.81	100.68	101.98	101.33	106.13	113.13	109.63	115.32	116.87	116.09
T ₁₄ , 5.0 tonnes/ha FYM + 5.0 kg Zinc	48.20	49.70	48.95	81.24	81.74	81.49	93.02	93.92	93.47	93.76	96.06	94.91
T ₁₅ , 5.0 tonnes/ha FYM + Biochar	49.32	50.32	49.82	82.74	83.04	82.89	93.92	94.09	94.005	94.34	96.74	95.54
T ₁₆ , 5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar	51.22	51.82	51.52	83.55	84.45	84.00	95.18	95.87	95.525	96.24	97.54	96.89
CD (P=0.05)	6.05	6.12	7.05	5.00	9.07	8.54	9.34	12.05	10.76	11.39	10.68	10.61
SEM±	2.16	1.75	1.72	1.72	3.31	2.89	3.12	4.10	3.66	3.60	3.35	4.02
SED	3.06	2.47	2.43	2.43	4.69	4.08	4.42	5.80	5.18	5.09	4.74	5.68
C.V.	6.34%	5.87%	6.02%	6.78%	6.75%	6.00%	7.45%	7.00%	7.85%	8.19%	6.90%	7.56%

Table 2. Effect of organic manure, inorganic fertilizer and biochar on number of tillers/m² at 30, 60, 90 DAT and at harvest of rice during 2023 and 2024

Treatment	Number of tillers/m ²											
	2023		2024		2023		2024		2023		2024	
	30 DAT	Mean	60 DAT	Mean	90 DAT	Mean	90 DAT	Mean	At Harvest	2023 At Harvest	2024 At Harvest	Mean
T ₁ , Control	180.43	181.03	256.37	257.22	264.78	265.83	266.88	264.78	265.83	252.43	255.43	253.93
T ₂ , 50% RDF	184.65	185.55	260.14	261.23	269.72	270.62	271.52	269.72	270.62	257.32	259.22	258.27
T ₃ , 75% RDF	188.07	189.12	274.03	275.03	283.21	284.21	285.21	283.21	284.21	273.47	276.07	274.77
T ₄ , 100% RDF	191.23	192.23	292.63	293.62	299.01	300.11	301.21	299.01	300.11	291.84	293.24	292.54
T ₅ , 50% RDF +5.0 tonnes/ha FYM + 5.0 kg Zinc	189.60	190.75	278.82	279.77	298.11	299.16	300.21	298.11	299.16	276.61	278.71	277.66
T ₆ , 75% RDF +5.0 tonnes/ha FYM + 5.0 kg Zinc	196.67	197.57	301.18	302.23	311.12	311.62	312.12	311.12	311.62	299.31	301.81	300.56
T ₇ , 100% RDF +5.0 tonnes/ha FYM + 5.0 kg Zinc	199.54	200.39	307.26	308.26	320.02	321.02	322.02	320.02	321.02	304.28	306.28	305.28
T ₈ , 50% RDF +5.0 tonnes/ha FYM + Biochar	196.20	197.2	302.87	303.62	318.33	319.48	320.63	318.33	319.48	301.20	303.24	302.22
T ₉ , 75% RDF +5.0 tonnes/ha FYM + Biochar	201.42	202.37	310.57	311.42	329.76	330.66	331.56	329.76	330.66	306.48	308.88	307.68
T ₁₀ , 100% RDF +5.0 tonnes/ha FYM + Biochar	208.11	209.26	316.98	317.98	337.84	338.84	339.84	337.84	338.84	312.67	315.17	313.92
T ₁₁ , 50% RDF +5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar	219.10	220.1	336.43	337.45	364.63	365.68	366.74	364.63	365.68	329.30	331.35	330.32
T ₁₂ , 75% RDF + 5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar	226.20	227.7	351.34	352.84	384.31	385.81	387.31	384.31	385.81	350.61	353.61	352.11
T ₁₃ , 100% RDF +5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar	235.36	236.86	376.38	378.51	401.13	402.79	404.45	401.13	402.79	375.51	378.34	376.92
T ₁₄ , 5.0 tonnes/ha FYM + 5.0 kg Zinc	182.54	183.39	255.37	256.34	270.02	271.62	273.22	270.02	271.62	254.28	256.38	255.33
T ₁₅ , 5.0 tonnes/ha FYM + Biochar	187.45	188.45	263.57	265.04	283.53	284.33	285.13	283.53	284.33	261.20	264.22	262.71
T ₁₆ , 5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar	192.12	193.62	273.66	273.66	285.34	286.84	288.34	285.34	286.84	271.13	272.46	271.79
CD (P=0.05)	17.23	19.73	34.20	24.91	276.10	31.65	27.18	276.10	31.65	33.08	35.47	30.38
SEM±	5.90	6.49	15.56	9.66	9.38	10.61	9.76	9.38	10.61	11.11	12.63	10.17
SED	8.34	9.17	17.76	13.66	13.27	15.01	13.80	13.27	15.01	15.71	17.86	14.38
C.V.	6.24%	7.09%	8.32%	9.02%	6.18%	7.84%	7.23%	6.18%	7.84%	8.01%	8.87%	7.05%

Table 3. Effect of organic manure, inorganic fertilizer and biochar on dry matter accumulation (g/m^2) at various growth stages of rice during 2023 and 2024

Treatment	Dry matter accumulation (g/m^2)											
	2023		2024		Mean		2023		2024		Mean	
	30 DAT	30 DAT	60 DAT	60 DAT	90 DAT	90 DAT	At Harvest	At Harvest	90 DAT	90 DAT	At Harvest	At Harvest
T ₁ , Control	243.29	245.29	244.29	341.56	344.50	343.03	458.34	462.34	460.34	668.02	675.02	671.52
T ₂ , 50% RDF	256.23	258.23	257.23	359.06	361.26	360.16	467.65	470.21	468.93	674.06	679.06	676.56
T ₃ , 75% RDF	260.67	262.07	261.37	364.75	367.25	366.00	478.51	482.51	480.51	683.53	689.13	686.33
T ₄ , 100% RDF	268.47	270.57	269.52	379.52	382.12	380.82	501.47	505.07	503.27	703.27	709.37	706.32
T ₅ , 50% RDF + 5.0 tonnes/ha FYM + 5.0 kg Zinc	266.79	268.79	267.79	376.70	379.30	378.00	490.34	494.24	492.29	701.29	707.00	704.14
T ₆ , 75% RDF + 5.0 tonnes/ha FYM + 5.0 kg Zinc	274.24	276.93	275.58	386.63	389.60	388.11	523.34	527.32	525.33	738.08	744.21	741.14
T ₇ , 100% RDF + 5.0 tonnes/ha FYM + 5.0 kg Zinc	287.96	289.35	288.65	428.27	431.62	429.94	608.76	612.26	610.51	789.56	795.01	792.28
T ₈ , 50% RDF + 5.0 tonnes/ha FYM + Biochar	276.34	278.04	277.19	400.80	403.20	402.00	601.60	604.50	603.05	761.66	767.05	764.35
T ₉ , 75% RDF + 5.0 tonnes/ha FYM + Biochar	293.70	295.36	294.53	448.23	451.33	449.78	622.62	624.22	623.42	821.42	826.02	823.72
T ₁₀ , 100% RDF + 5.0 tonnes/ha FYM + Biochar	300.36	302.21	301.28	416.67	419.23	417.95	648.33	652.13	670.5	856.21	862.01	859.11
T ₁₁ , 50% RDF + 5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar	294.69	296.28	295.48	403.62	406.12	404.87	646.70	650.10	648.4	845.59	851.50	848.54
T ₁₂ , 75% RDF + 5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar	310.58	312.58	311.58	456.56	459.64	458.10	639.49	643.40	641.44	857.12	863.36	860.24
T ₁₃ , 100% RDF + 5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar	326.39	328.23	327.31	472.73	475.01	473.87	668.79	672.21	650.23	874.36	880.03	877.19
T ₁₄ , 5.0 tonnes/ha FYM + 5.0 kg Zinc	252.41	254.01	253.21	363.52	366.47	364.99	463.47	467.24	465.35	670.48	676.40	673.44
T ₁₅ , 5.0 tonnes/ha FYM + Biochar	261.39	263.17	262.28	370.32	373.02	371.67	472.29	476.15	474.22	685.59	691.32	688.45
T ₁₆ , 5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar	264.57	266.02	265.29	379.63	382.24	380.93	478.65	482.15	480.4	696.18	701.06	698.62
CD (P=0.05)	25.29	34.76	32.59	34.50	40.26	38.00	40.56	53.45	54.31	73.61	70.70	80.11
SEM±	9.87	10.65	9.24	12.29	14.98	12.94	17.16	20.24	18.46	24.45	25.52	28.43
SED	13.95	15.06	13.07	17.38	21.18	18.30	24.27	28.62	26.10	34.58	36.08	40.21
C.V.	7.16%	7.09%	6.87%	7.30%	7.49%	6.63%	7.42%	8.45%	6.81%	6.63%	6.84%	8.53%

matter accumulation observed under T_{13} reflects enhanced photosynthetic efficiency, greater leaf area development and improved assimilate production and translocation. The synergistic interaction among organic manure, inorganic fertilizers and biochar likely facilitated improved carbon assimilation and biomass partitioning towards vegetative organs, ultimately resulting in higher dry matter production. These findings corroborate the results of Kumar *et al.* (2019) who reported increased biomass accumulation in rice under integrated nutrient management systems. The present results are in close agreement with Patel *et al.* (2022) who emphasized that integrated nutrient application not only improves growth parameters but also contributes to sustainable soil fertility, long term productivity and enhanced crop resilience.

Yield and Yield attributes: The data presented in the table 4 clearly reveal that the integrated application of organic (FYM), inorganic (RDF and zinc), and biochar significantly influenced all the yield attributes of the crop over the two-year study (2023–2024). Panicle length, number of grains panicle⁻¹, test weight and effective tillers showed a consistent increasing trend with the progressive integration of nutrient management. The maximum panicle length (35.10 cm in 2023 and 35.34 cm in 2024) and pooled basis is 35.22 cm, number of grains/panicle (179 in 2023 and 182 in 2024) and pooled basis is 181.50, test weight (23.54 g in 2023 and 23.64 g in 2024) test weight on the pooled basis is 23.59 g and effective tillers (354/m² in 2023 and 358/m² in 2024) and pooled basis is 356/m² were recorded in treatment T_{13} (100% RDF + 5 t/ha FYM + 5 kg Zn + biochar), which was significantly higher than the control (T_1). This result demonstrates the beneficial role of combined nutrient sources in improving the reproductive growth of the crop. The two-year study period (2023–2024), corroborating findings by Yadav *et al.* (2020), who reported similar enhancements in yield components under integrated nutrient management. The application of RDF alone (T_4) improved the attributes over the control but was still inferior to treatments involving organic supplements and micronutrients. Among the integrated treatments, T_{12} and T_{11} (involving 75% and 50% RDF with FYM, Zn, and biochar) also performed considerably well, indicating that even partial substitution of RDF with organic and micronutrient inputs can enhance grain formation and quality (Patel *et al.*, 2022).

Biological Yield and Harvest Index: The data presented in Table 5 clearly indicate that biological yield of rice increased progressively with enhanced nutrient management with marked differences among treatments. The maximum biological yield was recorded under T_{13} (100% RDF + 5 t ha⁻¹ FYM + 5 kg Zn + biochar) registering 143.84 q ha⁻¹ in 2023 and 144.64 q ha⁻¹ in 2024 with a

pooled mean of 144.24 q ha⁻¹. This treatment significantly outperformed the control (T_1) which recorded the lowest biological yield (75.72 q ha⁻¹ in 2023 and 76.22 q ha⁻¹ in 2024; pooled mean 75.97 q ha⁻¹). The substantial enhancement in biological yield under T_{13} reflects the cumulative and synergistic effects of balanced inorganic fertilization supplemented with organic amendments, biochar and micronutrient zinc, which together improve nutrient availability, uptake efficiency and overall plant vigor. The integrated application of FYM and biochar likely improved soil physical properties such as aggregation, aeration and moisture retention, while also enhancing microbial activity and nutrient cycling. Zinc supplementation further contributed by facilitating key physiological processes including enzyme activation, protein synthesis and chlorophyll formation thereby promoting higher photosynthetic rates and greater biomass accumulation (Yadav *et al.*, 2017). Similar trends were observed in treatments T_{12} and T_{10} , which also recorded comparatively higher biological yields (140.95 and 136.12 q ha⁻¹, respectively) underscoring the beneficial role of integrated nutrient supply over sole application of inorganic fertilizers.

The harvest index an important indicator of the efficiency with which total biomass is converted into economic yield, ranged from 46.93% in the control to 49.06% in T_{13} . Although variations in harvest index were narrower compared to biological yield the relatively higher values under integrated nutrient treatments suggest improved assimilate partitioning towards grain formation. The highest harvest index recorded under T_{13} , followed closely by T_{12} , T_{11} and T_{09} , indicates that the combined use of organic manures, biochar and balanced fertilization not only enhanced total biomass production but also optimized source sink relationships. These findings are in agreement with Choudhary *et al.* (2016) who reported improved harvest index in rice under integrated nutrient management due to enhanced translocation of photosynthate from vegetative parts to grains. The results highlight that integrated nutrient management practices particularly those combining organic amendments, micronutrients and biochar with recommended fertilizer doses, are effective in maximizing biological yield while maintaining efficient biomass partitioning in rice.

The present investigation clearly demonstrates that integrated nutrient management combining chemical fertilizers with organic amendments and micronutrients plays a pivotal role in enhancing rice productivity and soil health. The conjoint application of RDF, farm yard manure, zinc and biochar significantly improved crop growth, yield attributes and yield compared to the sole application of inorganic fertilizers. Among the different nutrient management treatments T_{13} (100% RDF + 5.0 t ha⁻¹ FYM + 5.0 kg ha⁻¹ Zn +

Table 4. Effect of organic manure, inorganic fertilizer and biochar on yield attributes of rice during 2023 and 2024

Treatment	Yields attributes											
	Panicle length (cm)		Mean	Number of grains/panicles		Mean	Test weight (g)		Mean	Number of effective tillers (m ²)		
	2023	2024		2023	2024		2023	2024		2023	2024	
T ₁ , Control	30.10	30.18	30.14	105	106	105.50	20.10	20.15	20.125	235	237	236
T ₂ , 50% RDF	30.62	30.76	30.69	119	123	121.00	21.20	21.26	21.23	249	253	251
T ₃ , 75% RDF	31.20	31.33	31.26	128	132	130.00	21.42	21.48	21.45	276	278	277
T ₄ , 100% RDF	32.10	32.15	32.12	135	138	136.50	21.61	21.67	21.64	279	281	280
T ₅ , 50% RDF +5.0 tonnes/ha FYM + 5.0 kg Zinc	31.30	31.45	31.37	132	136	134.00	21.58	21.64	21.61	281	283	282
T ₆ , 75% RDF +5.0 tonnes/ha FYM + 5.0 kg Zinc	31.60	31.87	31.73	141	144	142.50	21.86	21.92	21.89	297	299	298
T ₇ , 100% RDF +5.0 tonnes/ha FYM + 5.0 kg Zinc	32.32	32.78	32.55	148	152	150.00	22.04	22.11	22.075	300	302	301
T ₈ , 50% RDF +5.0 tonnes/ha FYM + Biochar	32.21	32.45	32.33	142	147	144.50	22.00	22.18	22.09	305	308	306.5
T ₉ , 75% RDF +5.0 tonnes/ha FYM + Biochar	32.78	32.97	32.87	152	156	154.00	22.25	22.35	22.3	316	319	317.5
T ₁₀ , 100% RDF +5.0 tonnes/ha FYM + Biochar	33.50	33.67	33.58	159	163	161.00	22.64	22.69	22.665	330	336	333
T ₁₁ , 50% RDF +5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar	33.40	33.89	33.64	157	160	158.50	22.87	22.97	22.92	339	343	341
T ₁₂ , 75% RDF + 5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar	34.32	34.65	34.48	168	171	169.50	23.12	23.21	23.165	347	351	349
T ₁₃ , 100% RDF +5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar	35.10	35.34	35.22	179	182	180.50	23.54	23.64	23.59	354	358	356
T ₁₄ , 5.0 tonnes/ha FYM + 5.0 kg Zinc	30.50	30.78	30.64	108	112	110.00	20.97	21.02	20.995	290	296	293
T ₁₅ , 5.0 tonnes/ha FYM + Biochar	30.89	31.09	30.99	117	119	118.00	21.20	21.25	21.225	302	307	304.5
T ₁₆ , 5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar	31.54	31.86	31.70	126	128	127.00	21.88	21.98	21.93	311	316	313.5
CD (P=0.05)	5.56	6.05	4.63	10.95	11.28	12.67	12.73	12.05	12.34	33.63	21.33	27.55
SEM±	1.23	1.64	1.26	5.18	4.46	6.88	0.96	0.71	0.81	15.11	10.85	13.00
SED	1.74	2.31	1.78	7.32	6.31	7.25	1.36	1.00	1.15	21.37	15.34	18.39
C.V.	7.00%	9.70%	7.75%	8.47%	6.45%	6.98%	7.56%	7.60%	8.40%	9.70%	8.18%	8.45%

Table 5. Effect of organic manure, inorganic fertilizer and biochar on yield Studies of rice during 2023 and 2024

Treatment	Yield studies											
	Grain yield (q/ha)		Straw yield (q/ha)		Biological yield (q/ha)		Harvest Index (%)		Mean			
	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024		
T ₁ , Control	35.11	35.98	35.545	40.12	40.24	40.18	75.23	76.22	75.72	46.67	47.20	46.93
T ₂ , 50% RDF	45.75	46.11	45.93	50.32	51.08	50.7	96.07	97.19	96.63	47.62	47.44	47.53
T ₃ , 75% RDF	54.76	55.06	54.91	58.98	60.30	59.64	113.74	115.36	114.55	48.14	47.72	47.93
T ₄ , 100% RDF	62.56	63.34	62.95	67.01	68.35	67.68	129.57	131.69	130.63	48.28	48.09	48.18
T ₅ , 50% RDF +5.0 tonnes/ha FYM + 5.0 kg Zinc	53.80	54.53	54.165	58.28	59.03	58.65	112.08	113.56	112.82	48.00	48.01	48.00
T ₆ , 75% RDF +5.0 tonnes/ha FYM + 5.0 kg Zinc	62.12	62.20	62.16	66.59	67.50	67.04	128.71	129.7	129.20	48.26	48.11	48.18
T ₇ , 100% RDF +5.0 tonnes/ha FYM + 5.0 kg Zinc	63.27	64.17	63.72	67.87	68.54	68.20	131.14	132.71	131.92	48.19	48.35	48.27
T ₈ , 50% RDF +5.0 tonnes/ha FYM + Biochar	57.30	58.10	57.7	61.51	62.37	61.94	118.81	120.47	119.64	48.42	48.22	48.32
T ₉ , 75% RDF +5.0 tonnes/ha FYM + Biochar	64.83	65.09	64.96	68.16	69.20	68.68	132.99	134.29	133.64	48.74	48.46	48.60
T ₁₀ , 100% RDF +5.0 tonnes/ha FYM + Biochar	66.22	66.62	66.42	69.20	70.20	69.70	135.42	136.82	136.12	48.89	48.69	48.79
T ₁₁ , 50% RDF +5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar	61.84	63.74	62.79	65.08	66.98	66.03	126.92	130.72	127.77	48.72	48.76	48.74
T ₁₂ , 75% RDF + 5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar	68.84	70.44	69.64	72.10	73.32	72.71	140.94	143.76	140.95	48.84	48.99	48.91
T ₁₃ , 100% RDF +5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar	71.55	72.35	71.95	74.29	75.10	74.69	145.84	147.45	146.64	49.06	49.06	49.06
T ₁₄ , 5.0 tonnes/ha FYM + 5.0 kg Zinc	44.23	45.43	44.83	49.42	50.68	50.05	93.65	96.11	94.88	47.22	47.26	47.24
T ₁₅ , 5.0 tonnes/ha FYM + Biochar	47.12	48.56	47.84	52.40	53.10	52.75	99.52	101.66	100.59	47.34	47.76	47.55
T ₁₆ , 5.0 tonnes/ha FYM + 5.0 kg Zinc + Biochar	52.87	54.07	53.47	57.35	58.05	57.70	110.22	112.12	111.17	47.96	48.22	48.09
CD (P=0.05)	6.79	6.67	7.22	8.29	7.35	5.51	11.23	12.32	13.81	12.10	8.34	9.14
SEM±	2.00	1.96	2.15	1.83	2.20	2.25	3.54	3.92	4.09	2.11	2.20	2.13
SED	2.83	2.78	3.04	2.59	3.11	3.19	5.01	5.54	5.78	2.99	3.11	3.01
CV	8.04%	7.92%	8.09%	7.18%	9.47%	8.33%	6.20%	8.05%	7.96%	8.61%	7.34%	8.67%

biochar) consistently recorded superior performance in terms of panicle length, number of grains per panicle, grain weight, test weight, biological yield (144.64 q ha⁻¹) and harvest index (48.35%). The enhanced yield under T₁₃ can be attributed to improved nutrient availability, better nutrient use efficiency and improved soil physico chemical and biological properties resulting from the synergistic interaction of organic and inorganic inputs. Biochar application likely improved soil structure, moisture retention and microbial activity, thereby facilitating sustained nutrient supply throughout the crop growth period. Zinc supplementation further enhanced physiological and metabolic processes essential for grain development. The results validate the effectiveness of integrated nutrient management in promoting higher productivity while maintaining soil fertility and ecological balance. Therefore, adoption of integrated nutrient management practices is essential for achieving sustainable rice production, improving resource use efficiency and ensuring long term agricultural sustainability in rice based cropping systems.

REFERENCES

- Bhatt, M.K., Labanya, R. and Joshi, H.C. 2019. Influence of long-term chemical fertilizers and organic manures on soil fertility-A review. *Universal Journal of Agricultural Research* 7(5): 177–188.
- Choudhary, A.K., Suri, V.K. and Chaudhari, S.K. 2016. Integrated nutrient management for sustainable agriculture and soil health. *Indian Journal of Agronomy* 61(4): 265–273.
- Ghorbani, M., Neugschwandtner, R.W., Konvalina, P., Asadi, H., Kopecký, M. and Amirahmadi, E. 2023. Comparative effects of biochar and compost applications on water holding capacity and crop yield of rice under evaporation stress: A 2-years field study. *Paddy and Water Environment* 21(1): 47–58.
- Hussain, M., Farooq, M., Nawaz, A., Al-Sadi, A.M., Solaiman, Z.M., Alghamdi, S.S. and Siddique, K.H. 2017. Biochar for crop production: potential benefits and risks. *Journal of Soils and Sediments* 17: 685–716.
- NRRI Research Bulletin No. 22, 2020. <https://icar-nrri.in/wpcontent/uploads/2020/05/NRRI-Research-Bulletin-22>.
- Kumar, P., Sharma, S. and Verma, A. 2019. Role of zinc and organic amendments in enhancing rice productivity. *Indian Journal of Agronomy* 64(4): 398–404.
- Nandy, S.N., Dhyani, P.P. and Samal, P.K. 2006. Resource information database of the Indian Himalaya (pp. 27–30). Almora: Environmental Information System on Himalayan Ecology, GP Institute of Himalayan Environment and Development.
- Oladele, S.O., Adeyemo, A.J. and Awodun, M.A. 2019. Influence of rice husk biochar and inorganic fertilizer on soil nutrients availability and rain-fed rice yield in 2 contrasting soils. *Geoderma* 336: 1–11.
- Patel, D., Jat, R.K. and Solanki, N.S. 2022. Optimizing nutrient use in rice through integrated approaches. *International Journal of Agriculture Sciences* 14(3): 22–28.
- Riaz, M., Khalid, M., Batoool, A., Abbas, A., Amjad, I., Kashif, M. and Shakeel, A. 2024. Hybrid rice suitability and future prospects. *Journal of Physical, Biomedical and Biological Sciences* 2024(1): 32–32.
- Sangeetha, J., Thangadurai, D., Fayeun, L.S., Akinwale, J.A., Habeeb, J., Maxim, S.S. and Islam, S. 2020. Origin and evolution of rice as domesticated food crop. Rice research for quality improvement: Genomics and genetic engineering: Volume 1: *Breeding Techniques and Abiotic Stress Tolerance*: 1–14.
- Yadav, R.K., Meena, V.S. and Lal, B. 2020. Integrated nutrient management in rice for improving yield and soil fertility. *Journal of Plant Nutrition*: 43(2): 245–255.
- Yadav, R.L. Dwivedi, B.S. and Prasad, K. 2017. Integrated nutrient management for sustaining crop productivity and improving soil health in intensively cultivated systems. *Indian Journal of Fertilisers* 13(6): 40–52.