



Impact of Biochar, Organic Manures and Inorganic Fertilizers on Nutrient Uptake and Yield in Rice Crop

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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 at Agricultural college Farm, Bapatla during 2023-2024 to study the effect of biochar, organic manures and inorganic fertilizers on nutrient uptake and yield of rice crop. The experiment was laid out in randomized block design with eight treatments and three replications. The treatments consist of 100% RDF in combination with organic manures (poultry manure, green leaf manure and FYM) and biochar. Data on N, P and K uptake by grain and straw at harvest and grain and straw yield were recorded. Results revealed that the rice grain and straw yield (kg ha^{-1}) was maximum in treatment T_5 i.e., 100% RDF + poultry manure @ 5 t ha^{-1} (6041) and minimum in control T_1 - 100% RDF (5013). The rice grain N and P uptake was maximum in T_5 (74.25, 40.56 kg ha^{-1} in 2023 and 76.48, 42.56 in 2024), and minimum in T_1 (48.45, 27.24 kg ha^{-1} in 2023 and 52.24, 30.78 in 2024), respectively. Similarly, rice straw N and P uptake was maximum in T_5 (76.48, 25.40 kg ha^{-1} in 2023 and 78.83, 29.93 in 2024) and minimum in T_1 (49.29, 15.98 kg ha^{-1} in 2023 and 51.62, 18.35 in 2024), respectively. Finally, it can be recommended that rice grain and straw yield was maximum in combined application of both inorganic and organic sources of nutrients compared to inorganic fertilizers alone.

Keywords: Biochar; inorganic fertilizers; organic manures; nutrient uptake and yield.

1. INTRODUCTION

“The major challenge in the 21st century will be feeding the world's growing population with the limited land resources. Rice (*Oryza sativa* L.) is one of the most predominant cereal food crops in about 40 countries in the world. Recently, a noticeable decline in production of rice in many of the intensively cultivated areas has been observed. The yield decline is attributed to soil degradation through nutrient depletion and loss of soil quality. It is apparent that sustainability of crop production system in future mainly depends to a large measure on the adequacy and balanced supply of nutrients” (Baskar, 2003). “Indiscriminate use of high analysis chemical fertilizers increases the crop yield in the initial years, but it is leading to development of several problems like decline in soil organic matter, increase in salinity, soil pollution and reduction of soil productivity” (Chakraborti and Singh, 2004). “The current decline in soil organic matter levels in many potential areas of rice production is a matter of great concern for India and Andhra Pradesh. Hence, to sustain rice production and ensure food security with these challenges, new adaptation strategies need to be developed and up-scaled. To compensate this, there is a need to develop Integrated Nutrient Management (INM) system. Sustainable soil management emphasizes use of organic manures and crop residues for maximizing profitability and maintaining environmental quality. The concept of integrated nutrient management seeks to sustain soil fertility through an integration of different nutrient sources and their application methods which produce maximum crop yield per

unit input use” (Bastia, 2002). A judicious combination of organic sources and inorganics has been found to mutually reinforce the efficiency of both the sources resulting in higher productivity and soil fertility.

2. MATERIALS AND METHODS

2.1 Experimental Site Description

A study was conducted at Agricultural College Farm, Bapatla located at an altitude of 5.49 m above mean sea level, 15°54' North latitude, 80°30' East longitude and about 8 km away from Bay of Bengal. It is located in Krishna agro-climatic zone of Andhra Pradesh. The results of the initial soil analytical data indicated that the experimental soil was sandy clay loam in texture, neutral in reaction (7.20), low in organic carbon (0.46%) and available nitrogen (215 kg ha^{-1}), and medium in available phosphorus (39.69 kg ha^{-1}) and high in potassium (387 kg ha^{-1}), while all micro-nutrients (Fe, Mn, Zn and Cu) were above critical levels.

2.2 Experimental Design and Treatments

Three different types of organic manures viz. Farmyard manure (FYM), poultry manure (PM), green leaf manure (Gliricidia leaves) and maize stalk (MS) biochar were used. The total number of treatments was 8, and the treatment was distributed in randomized block design (RBD) with three replications per treatment. The treatments were T_1 : 100%RDF (recommended dose of fertilizer-120-60-40 kg NPK); T_2 : 100%

RDF + Biochar @ 2.5 t ha⁻¹; T₃: 100% RDF + Green leaf manure (Gliricidia) @ 10 t ha⁻¹; T₄: 100% RDF + Co-Compost (Biochar: GLM @ 25:75); T₅: 100% RDF + Poultry manure @ 5 t ha⁻¹; T₆: 100% RDF + Co-Compost (Biochar: Poultry manure @ 25: 75); T₇: 100% RDF + FYM 10 t ha⁻¹; T₈: 100% RDF + Co-Compost (Biochar: FYM @ 25:75). The variety BPT-5204 was used. Recommended dose of inorganic fertilizers 120:60:40 kg N:P₂O₅:K₂O ha⁻¹, respectively was applied as per the treatments. Data on nutrient uptake and yield was recorded at harvest of crop.

2.3 Grain and Straw Yield

At maturity, the border rows from each plot were harvested first, leaving the net plot area. Later, the crop in each plot was harvested after separating the plants designated for recording biometric observations. The crop harvested from net plot area was threshed separately using pedal operated rice thresher for recording grain and straw yields. Both grain and straw from each plot was dried under sun separately to a constant weight before recording their final weights.

2.4 Plant Analysis Details

2.4.1 Collection and preparation of plant samples

The plant samples collected at harvest were washed with dilute HCl and then with double distilled water. The samples were shade dried initially and then oven dried at 65°C temperature and powdered using willey mill. One gram of powdered plant sample was taken in 150 ml Erlenmeyer flask and digested with diacid mixture (HNO₃ and HClO₄ in 9:4 ratio). The sample digest was filtered through Whatman No. 42 filter paper by washing the residue with double glass distilled water till chloride free and made up to 100 mL volume and the clear extract was used for the determination of different nutrients. The nitrogen content in rice plant was estimated by micro Kjeldahl distillation method (Piper, 1966). Phosphorus in the diacid extract of plant samples was estimated by vanado molybdo phosphoric yellow colour method using spectrophotometer at 420 nm wave length as described by Jackson (1973). Potassium in the diacid extract of plant samples was determined using flame photometer as per the method described by Jackson (1973). The data was statistically analyzed using randomized block design (Gomez and Gomez, 1984) and means were tested for significance.

3. RESULTS AND DISCUSSION

3.1 Grain Yield

“Close examination of data presented in the table 1 revealed that there was significant influence of various nutrient management treatments applied to *kharif* rice on grain yield during both the years of study. Among all the treatments, application of 100% RDF + PM @ 5 t ha⁻¹ (T₅- 6041 kg ha⁻¹ in 2023 and 6190 kg ha⁻¹ in 2024) recorded significantly highest grain yield which was on par with the treatments that received 100% RDF + Co-Compost (Biochar: PM @ 25: 75) (T₆- 5871 kg ha⁻¹ in 2023 and 5958 kg ha⁻¹ in 2024), 100% RDF + Green leaf manure (GLM) @ 10 t ha⁻¹ (T₃- 5812 in 2023 and 5905 kg ha⁻¹ in 2024), 100% RDF + FYM @ 10 t ha⁻¹ (T₇- 5738 kg ha⁻¹ in 2023 and 5815 kg ha⁻¹ in 2024) , 100% RDF + Co-Compost (Biochar: GLM @ 25: 75) (T₄-5602 in 2023 and 5699 kg ha⁻¹ in 2024) and 100% RDF + Co-Compost (Biochar: FYM @ 25: 75) (T₈-5523 in 2023 and 5646 kg ha⁻¹ in 2024) during both the years of study, respectively. The lowest grain yield was recorded in the treatment T₁ *i.e.*, 100% RDF (5013 and 5101 kg ha⁻¹) during 2023 and 2024, respectively. The results revealed that combined application of organics and inorganics recorded significantly highest yields which could be due to higher nutrient uptake and improvement of soil environment” (Krishna et al., 2007, Humne et al., 2008, Deekshitha et al., 2021 and Surya Krishna 2022).

“Combined application of organics and inorganics were beneficial in reducing the fixation or precipitation of nutrients with those of soil components and played complementary role to boost the crop yield. Economic yield is a fraction of total biological yield of the crop and drymatter accumulation, which is an important determinant of the grain yield” (Dhiman et al., 2000). “Total drymatter accumulation may reflect on economic yield in view of the fact that vegetative part of the plant serves as the source, whereas the spikelets serve as sink. During the vegetative growth stage, accumulation of drymatter and its distribution to yield attributes during reproductive stage through a process of translocation from source to sink and finally determine the economic yield of the crop” (Raju and Reddy, 2000).

Swathi et al. (2024) had reported that poultry manure is an excellent organic fertilizer,

containing high nitrogen, phosphorus, potassium and other essential nutrients. It also indicated that poultry manure more readily supplies P to plants than any other organic manure sources (babu et al., 2021). The increased grain yield in poultry manure treatments might be due to integrated application of poultry manure with inorganic nutrients improved the soil's physical, chemical and biological environment, which encouraged the proliferation of roots, resulting in more absorption water and nutrients from a larger area and depth, resulting in improvement in growth characters like plant height, drymatter accumulation, higher yield attributes viz., panicle length, number of filled grains and test weight. The improved growth and yield attributes contributed towards the increase in yield of rice in poultry manure plots. These results are in similar with the findings Jana et al. (2008), Abirami et al. (2024), Gehlot et al. (2024) and Swathi et al. (2024).

3.2 Straw Yield

The results of the investigation indicated that the combined use of organics and inorganics applied under rice crop significantly influenced the straw yield during the two years of study and the results were furnished in the Table 1.

Among all the treatments, application of 100% RDF + PM @ 5 t ha⁻¹ (T5- 6869 kg ha⁻¹ in 2023 and 7095 kg ha⁻¹ in 2024) recorded significantly highest straw yield which was on par with the treatments that received 100% RDF + Co-Compost (Biochar: PM @ 25: 75) (T6- 6669 kg ha⁻¹ in 2023 and 6986 kg ha⁻¹ in 2024), 100% RDF + Green leaf manure (GLM) @ 10 t ha⁻¹ (T3- 6627 in 2023 and 6909 kg ha⁻¹ in 2024), 100% RDF + FYM @ 10 t ha⁻¹ (T7- 6531 kg ha⁻¹ in 2023 and 6826 kg ha⁻¹ in 2024) , 100% RDF + Co-Compost (Biochar: GLM @ 25: 75) (T4- 6451 in 2023 and 6678 kg ha⁻¹ in 2024) and 100% RDF + Co-Compost (Biochar: FYM @ 25: 75) (T8- 6394 in 2023 and 6547 kg ha⁻¹ in 2024) during both the years of study, respectively. The lowest straw yield was recorded in the treatment T1 i.e., 100% RDF (5789 and 5934 kg ha⁻¹) during 2023 and 2024, respectively. Jana et al. (2008) who reported increased straw yields in rice with the combined application of PM and inorganic fertilizers. "This implies that by combining inorganic fertilizers with organic manures farmers could reduce the need for inorganic fertilizers and still increasing their productivity. The significant increase in straw yield in

response to the combined application of organic and inorganic fertilizers could be attributed to increased nutrient availability and thus increased uptake of nutrients by plant. This might be attributed to the nutrient supplying capacity of the organics as well as their propensity to improve the soil physico-chemical properties. Neither organics nor chemical fertilizers alone could be sufficient to increase yield sustainability under cropping system where nutrient turnover in soil plant system has been much higher" (Satyanarayana et al., 2002). However, in an integrated nutrient management, organics can maintain plant nutrients in the available forms for longer periods due to improved soil organic matter (SOM) and soil physico-chemical and biological characteristics. These results were in conformity with the findings of Jana et al. (2008) with combined application of green manures, FYM, PM, rice straw and chemical fertilizers.

"In general, use of organics in combination with chemical N maintained wet soil NH₄-N at higher levels throughout rice growth period than inorganic sources. Organics with inorganic N supply NH₄-N to the plant through continuous mineralization of organic N and in turn increase nutrient use efficiency, ultimately giving higher yield" (Manivannan and Sriramachandrasekharan, 2009). These results were in confirmation with the findings of Jana et al. (2008). Manjappa (2014), Prathibhasree et al. (2016), Deekshitha et al. (2021), Anji babu et al. (2022), Abirami et al. (2024) and Swathi et al. (2024).

3.3 Nitrogen Uptake

Close perusal of the data (Table 2) on N uptake in rice revealed that various nutrient management treatments imposed in *kharif* have shown significant influence on N uptake at harvest of rice during the two years of experimentation.

Irrespective of the year of study, application of 100% RDF+ PM @ 5 t ha⁻¹ i.e., T5 (74.25, 76.48 kg ha⁻¹ in 2023 and 77.98, 78.83 kg ha⁻¹ in 2024) recorded significantly highest N uptake at harvest (in grain and straw) stage over all other treatments and it was on par with T6 i.e., 100% RDF + Co-compost (biochar: PM @ 25:75) (71.49, 75.49 kg ha⁻¹ in 2023 and 75.44, 77.35 kg ha⁻¹ in 2024) and T₃ i.e., 100% RDF+ GLM @ 10 t ha⁻¹ (68.26, 70.46 kg ha⁻¹ in 2023 and 71.27, 74.19 kg ha⁻¹ in 2024).

Table 1. Effect of biochar, organic manures and inorganic fertilizers on grain yield (kg ha⁻¹) and straw yield (kg ha⁻¹) of rice

Treatments	Kharif 2023		Kharif 2024	
	Grain Yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Grain Yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)
T1 - 100% RDF	5013	5789	5101	5934
T2 - 100% RDF + Biochar @ 2.5 t ha ⁻¹	5069	5911	5147	6172
T3 - 100% RDF + Green leaf manure (GLM) @ 10 t ha ⁻¹	5812	6627	5905	6909
T4 - 100% RDF + Co-Compost (Biochar: GLM @ 25: 75)	5602	6451	5699	6678
T5 - 100% RDF + Poultry manure @ 5 t ha ⁻¹	6041	6869	6190	7095
T6-100% RDF + Co-Compost (Biochar : Poultry manure @ 25:75)	5871	6669	5958	6986
T7 - 100% RDF + FYM @ 10 t ha ⁻¹	5738	6531	5815	6826
T8 - 100% RDF + Co-Compost (Biochar: FYM @ 25:75)	5523	6394	5646	6547
SEm±	222.6	223.0	230.2	240.4
CD (P=0.05)	675.2	676.42	698.3	729.3
CV (%)	6.90	6.03	7.01	6.27

The lowest N uptake (48.45, 49.29 kg ha⁻¹ and 52.24, 51.62 kg ha⁻¹) at harvest (in grain, straw) stage in 2023 and 2024, respectively was recorded in the treatment T1 that received 100% RDF.

“Among the manures without biochar treatment, rice grain and straw nitrogen uptake was maximum in poultry manure treatment compared to other manures. The results also showed that among the manures with biochar treatment the grain and straw nitrogen uptake was maximum in poultry manure and biochar co-compost compared to other manure and biochar co-compost. The increase in N uptake could be ascribed to slow and continuous supply of the nutrients, coupled with reduced N losses via denitrification or leaching, which might have improved the synchrony between plant N demand and supply from the soil” (Haile et al., 2012 and Tilahun et al., 2013). “Application of organics in combination with inorganic fertilizers, exhibited better response in nutrient uptake over chemical fertilizer due to steady supply of nutrients throughout the growing period of crops” (Laxminarayana and Patiram, 2006). The uptake being the product of nutrient content and drymatter accumulation, the increase in N uptake by the crop might be due to increased availability of nitrogen and higher grain and straw yields. Similar results were also reported by Jana et al. (2008), Vijay and Yashbirsing (2012), Anji babu (2022), Surya Krishna et al. (2022), Das et al. (2024) and Swathi et al. (2024).

3.4 Phosphorus Uptake

The data presented in Table 3 indicated that different nutrient management treatments imposed have shown significant influence on the P uptake in rice at harvest stage during both the years of study.

The highest P uptake was recorded in the treatment T5 *i.e.*, 100% RDF+ PM @ 5 t ha⁻¹ with 40.56, 25.40 kg ha⁻¹ in 2023 and 42.56, 29.93 kg ha⁻¹ in 2024 in grain and straw, respectively and it was on par with treatment T6 (39.89, 24.80 kg ha⁻¹ in 2023 and 40.02, 28.68 kg ha⁻¹ in 2024) that received 100% RDF + Co-compost (biochar: PM @ 25:75) and T₃ *i.e.*, 100% RDF + GLM @ 10 t ha⁻¹ (36.26, 22.68 kg ha⁻¹ in 2023 and 38.87, 27.67 kg ha⁻¹ in 2024) at harvest (in grain, straw) stage of rice, respectively. The lowest P uptake (27.24, 15.98 kg ha⁻¹ in 2023 and 30.78, 18.35 kg ha⁻¹ in 2024) was recorded in the treatment T1 *i.e.*, 100% RDF at harvest stage (grain and straw) of crop growth.

“The increased P uptake could be due to higher drymatter accumulation as uptake being the product of nutrient content and drymatter accumulation. CO₂ produced during mineralization of organic sources play a vital role in solubilization of native P” (Nirukumari et al., 2013). The higher P uptake could be attributed to the increased P availability and increased

root growth of the crop. These results were in conformity with the findings of Das et al. (2024), Swahi et al. (2024) and Sofyan et al. (2025). The pH of the soil also indicated a positive change *i.e.*, a shift towards neutrality. This positive change enhanced the solubility of different nutrients especially phosphorus in the soil.

“The form of orthophosphate ion might have converted from PO_4^{3-} to HPO_4^{2-} or even $H_2PO_4^-$ for short periods, which resulted in increased concentration of P in the plants” (Das, 2000 and Tilahun et al., 2013). “The higher P uptake was attributed to the increased P availability and increased root growth of the crop” (Tilahun et al., 2013).

Table 2. Effect of biochar, organic manures and inorganic fertilizers on uptake of nitrogen (kg ha⁻¹) at harvest of rice

Treatments	Kharif 2023		Kharif 2024	
	Grain (kg ha ⁻¹)	Straw (kg ha ⁻¹)	Grain (kg ha ⁻¹)	Straw (kg ha ⁻¹)
T1 - 100% RDF	48.45	49.29	52.24	51.62
T2 - 100% RDF + Biochar @ 2.5 t ha ⁻¹	51.89	52.18	53.48	53.48
T3 - 100% RDF + Green leaf manure (GLM) @ 10 t ha ⁻¹	68.26	70.46	71.27	74.19
T4 - 100% RDF + Co-Compost (Biochar: GLM @ 25: 75)	63.38	64.68	66.86	69.18
T5 - 100% RDF + Poultry manure @ 5 t ha ⁻¹	74.25	76.48	77.98	78.83
T6-100% RDF + Co-Compost (Biochar : Poultry manure @ 25:75)	71.49	75.49	75.44	77.35
T7 - 100% RDF + FYM @ 10 t ha ⁻¹	64.73	65.34	67.24	71.46
T8 - 100% RDF + Co-Compost (Biochar: FYM @ 25:75)	59.91	61.83	63.69	62.83
SEm±	2.87	2.62	3.05	2.74
CD (P=0.05)	8.72	7.96	9.25	8.32
CV (%)	7.93	7.05	8.01	7.05

Table 3. Effect of biochar, organic manures and inorganic fertilizers on uptake of phosphorus (kg ha⁻¹) at harvest of rice

Treatments	Kharif 2023		Kharif 2024	
	Grain (kg ha ⁻¹)	Straw (kg ha ⁻¹)	Grain (kg ha ⁻¹)	Straw (kg ha ⁻¹)
T1 - 100% RDF	27.24	15.98	30.78	18.35
T2 - 100% RDF + Biochar @ 2.5 t ha ⁻¹	28.98	16.67	31.02	18.98
T3 - 100% RDF + Green leaf manure (GLM) @ 10 t ha ⁻¹	36.06	22.68	38.87	27.67
T4 - 100% RDF + Co-Compost (Biochar: GLM @ 25: 75)	33.28	20.40	36.50	25.46
T5 - 100% RDF + Poultry manure @ 5 t ha ⁻¹	40.56	25.40	42.56	29.93
T6-100% RDF + Co-Compost (Biochar : Poultry manure @ 25:75)	39.89	24.80	40.02	28.68
T7 - 100% RDF + FYM @ 10 t ha ⁻¹	34.82	21.04	37.24	25.82
T8 - 100% RDF + Co-Compost (Biochar: FYM @ 25:75)	31.78	18.90	34.28	22.24
SEm±	1.43	1.10	1.85	1.46
CD (P=0.05)	4.33	3.37	5.61	4.40
CV (%)	7.22	9.21	8.90	10.37

Table 4. Effect of biochar, organic manures and inorganic fertilizers on uptake of potassium (kg ha⁻¹) at harvest of rice

Treatments	Kharif 2023		Kharif 2024	
	Grain (kg ha ⁻¹)	Straw (kg ha ⁻¹)	Grain (kg ha ⁻¹)	Straw (kg ha ⁻¹)
T1 - 100% RDF	31.31	88.5	35.42	92.89
T2 - 100% RDF + Biochar @ 2.5 t ha ⁻¹	33.03	92.2	37.38	97.56
T3 - 100% RDF + Green leaf manure (GLM) @ 10 t ha ⁻¹	40.76	107.5	44.34	116.3
T4 - 100% RDF + Co-Compost (Biochar: GLM @ 25: 75)	38.82	103.8	42.49	110.8
T5 - 100% RDF + Poultry manure @ 5 t ha ⁻¹	46.64	117.9	49.64	128.4
T6-100% RDF + Co-Compost (Biochar : Poultry manure @ 25:75)	44.28	112.8	47.61	121.3
T7 - 100% RDF + FYM @ 10 t ha ⁻¹	37.34	101.9	41.71	106.48
T8 - 100% RDF + Co-Compost (Biochar: FYM @ 25:75)	35.89	98.5	39.44	102.37
SEm±	1.95	4.55	1.81	4.75
CD (P=0.05)	5.93	13.80	5.49	14.42
CV (%)	8.80	7.65	7.44	7.52

3.5 Potassium Uptake

Close examination of data related to potassium uptake in rice was presented in the table 4 and the results revealed that, different nutrient management treatments applied to *kharif* rice had shown significant influence on K uptake. Irrespective of the year of study, significantly highest K uptake was recorded in the treatment T₅ *i.e.*, 100% RDF + PM @ 5 t ha⁻¹ (46.64, 117.9 kg ha⁻¹ and 49.64, 128.4 kg ha⁻¹) at harvest (in grain, straw) stage during 2023 and 2024, respectively and it was on par with T₆ *i.e.*, 100% RDF + Co-compost (biochar: PM @ 25:75) (44.28, 112.8 kg ha⁻¹ in 2023 and 47.61, 121.3 kg ha⁻¹ in 2024), and T₃ *i.e.*, 100% RDF+ GLM @ 10 t ha⁻¹ (40.76, 107.5 kg ha⁻¹ and 44.34, 116.3 kg ha⁻¹) at harvest (in grain, straw) stage of rice during 2023 and 2024, respectively. The lowest potassium uptake was recorded in the treatment that received 100% RDF *i.e.*, T₁ (31.31 and 35.42 kg ha⁻¹ in grain at harvest and 88.5 and 92.89 kg ha⁻¹ in straw at harvest) during 2023 and 2024, respectively.

“The increase in uptake of potassium in combined application of organics and inorganics was due to the release of K from organic manures during decomposition and solubilisation and release of native and fixed forms of potassium, charging the soil solution with K⁺ ions” (Hemalatha et al., 2000). “Incorporation of organic manures have improved the soil environment, which encouraged proliferous root

system resulting in better absorption of nutrients from lower layers and thus resulting in higher yield and nutrient uptake” (Vinay, 2006). Nirukumari et al. (2013) noticed faster rate of mineralization and greater utilization of nutrients through the use of green manuring in combination with chemical fertilizer. Similar observations were reported for NPK uptake by Raghuvveer et al. (2015) and Surya Krishna, (2022).

4. CONCLUSION

Significantly higher grain yield, straw yield and nutrient uptake was recorded with application of organic sources along with inorganic sources compared to inorganic source alone. Among the organic manures without biochar application significantly higher grain yield, straw yield and nutrient uptake was recorded with poultry manure compared to other manures. Results also revealed that among the manures with biochar application highest grain yield, straw yield and nutrient uptake was maximum in treatment that received biochar and poultry manure co-compost compared to other co-compost treatments during the two years of study. The application of organic sources along with recommended dose of fertilizers in rice cultivation offers a sustainable and effective approach to enhance both yield and nutrient uptake. This integrated nutrient management strategy not only boosts soil productivity but also contributes to improved soil health and nutrient

use efficiency, making it beneficial practice for rice farmers.

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 writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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