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Growth and Nutrient Uptake of Organic *Basmati* Rice (*Oryza sativa* L.) as Influenced by Diversified Nutrient Sources

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ABSTRACT

A field experiment was conducted during the *kharif* (May–November, 2016) at ICAR-Indian Agricultural Research Institute, New Delhi, India to assess the growth response and nutrient uptake of organic *Basmati* rice (*Oryza sativa* L.) as influenced by diversified nutrient sources under a long-term field experiment. This long-term organic farming of the *Basmati* rice-wheat cropping system experiment was initiated in the year of 2003 and continued till 2016 with the same layout and treatments. Sixteen treatments comprising combinations of farmyard manure (FYM), green manures (*Sesbania* green manure, SGM, and *Leucaena* green leaf manuring, LGLM), blue-green algae (BGA), and *Azotobacter* were evaluated in a randomized block design with three replications. The combined application to both rice and wheat (T_{16}: SGM+FYM+BGA to rice and LGLM+FYM+*Azotobacter* to wheat) significantly improved plant height (112.6 cm), tiller number (568.5 m^{-2}), leaf area index (6.15), and dry matter accumulation (1350.3 g m^{-2} at 90 DAT). Application of T_{16} also recorded the highest uptake of N (125.3 kg ha^{-1}), P (16.4 kg ha^{-1}), and K (169.5 kg ha^{-1}), along with Fe (4,873.8 g ha^{-1}), Zn (1,902.3 g ha^{-1}), Mn (1,455.9 g ha^{-1}), and Cu (847.4 g ha^{-1}). The results highlighted that the integrated application of organic inputs enhanced growth, yield attributes, and nutrient uptake in organic *Basmati* rice cultivation. Our findings underscore the sustainable cultivation of organic *Basmati* rice with the application of diversified organic nutrient sources.

KEYWORDS: *Basmati*, growth, nutrients, organic, rice

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Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

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1. INTRODUCTION

Rice (*Oryza sativa* L.) is the stuff of life for more than half of humankind, a humble grain that feeds the world. It is the grain that has profoundly shaped the cultural traditions, culinary habits, and economic livelihoods of billions across the globe (Prasad et al., 2017). India is a natural repository for a multitude of long and short-grained aromatic rice, nurtured and conserved by the farmers of north-western sub-Himalayan regions for centuries. Among these, *Basmati* is known to be the world's most precious rice strain. The traditional *Basmati* varieties are tall, low-yielding types, photo-sensitive, and lodge under high doses of nitrogenous fertilizer (Critykar et al., 2019). Decline in factor productivity (Kumar et al., 2022), erosion of mineral nutrients and soil organic carbon content (Das et al., 2024), water-logging and soil salinization, high level of nitrate concentration in well water (Kumar and Sharma, 2020), etc., are a few consequences of the conventional rice-wheat cropping system. The paddy field ecosystem represents a unique aquatic-terrestrial habitat, which provides a favourable environment for growth and nitrogen fixation by cyanobacteria meeting their requirements for light, water, and elevated temperature and nutrient availability (Shivay et al., 2022). Cyanobacteria are well adapted to a diverse range of environmental conditions. They are widely used as inoculants for enhancing soil health, besides increasing crop yields, mainly in rice (Shahane et al., 2020; Shivay et al., 2022). A combination of cyanobacteria and PGPR through biofilm-based formulations might have synergism between them. This synergistic interaction reflects on higher plant growth-promoting action and increased availability and uptake of nutrients in biofilm formulation than their separate inoculation to rice needs to be studied. India's organic food market size reached US$ 1,917.4 million in 2024. The market is projected to reach US$ 10,807.9 million by 2033, exhibiting a growth rate (CGAR) of 20.13% during 2025–2033. The market growth is attributed to growing awareness regarding the health benefits of organic food products, rising consciousness regarding the health hazards associated with chemical pesticides and fertilizers, and increasing investments by Indian corporate firms in agritech, agribusinesses, and organic farming (https://www.imarcgroup.com/indian-organic-food-market). The latest report of the 2022 FiBL–IFOAM survey noted that India has 2.6 m ha under organic cultivation (the world's fifth largest), though this represents about 1.5% of the nation's total agricultural area. Over the past decade, organic land increased by 145.1% (Invest India). There is strong international demand for organic and high-quality agricultural products. India, with its diverse agro-climatic zones, rich agricultural biodiversity, skilled labor force, and longstanding tradition of organic farming, is well-positioned to take advantage of this opportunity. *Basmati* rice, in particular, earns up to three times more than non-*Basmati* varieties in both international and domestic markets due to its premium value. In 2016–17, India exported 4 million metric tonnes (mmt) of *Basmati* rice, earning ₹ 21,604.58 crores (http://apeda.gov.in/apedawebsite/SubHead_Products/Basmati_Rice.htm). Further, during the year 2023–24, India has exported 5.242 mmt of *Basmati* rice to the global market and earned 5,837.12 million US$. The major exported countries for *Basmati* rice from India were Saudi Arab, Iran, Iraq, the United Arab Emirates, the USA, and Yemen (https://apeda.gov.in/BasmatiRice). Therefore, we can say that Indian organic *Basmati* rice has great potential in the international market to earn more foreign money, provided we maintain International Standards for the *Basmati* rice production system. Hence, the experiment was done to assess the growth response and nutrient uptake of organic *Basmati* rice (*Oryza sativa* L.) under diversified nutrient sources.

2. MATERIALS AND METHODS

2.1. Experimental site, climatic conditions, and soil properties

The field experiment was carried out during the *kharif* (May 2016–November 2016) 2016 at the research farm (main block 14-C) of the ICAR-Indian Agricultural Research Institute (IARI), New Delhi. The experimental site is at an elevation of 228.61 m above the mean sea level and situated at a latitude and longitude of 28°38'23"N and 77°09'27"E, respectively. The climate of Delhi is a sub-tropical and semi-arid type with hot and dry summer and cold winter, which falls under the agro-climatic zone 'Trans-Gangetic plains'. The mean annual normal rainfall and evaporation are 650 and 850 mm, respectively.

In Delhi, the summer is usually hot and dry, and winter remains cold. May and June are the hottest months with temperatures ranging between 41°C and 48°C, while January remains the coldest month with temperatures ranging between 3°C and 7°C. The temperature started rising slowly from February and reached its maximum during June. There is a slight fall in temperature afterwards due to the advent of the South-West monsoon rains. Most of the precipitation is concentrated from July to September. The meteorological parameters recorded at the meteorological observatory of ICAR-IARI, New Delhi, during the crop growing season are presented in Figure 1. The total rainfall received during the rice growing season of 2016 was 1,338.6 mm. The rainfall was well distributed throughout the crop-growing season. Overall weather conditions in terms of sunshine hours, relative humidity, and minimum and maximum temperatures were favourable to the normal growth and development of the rice crop.

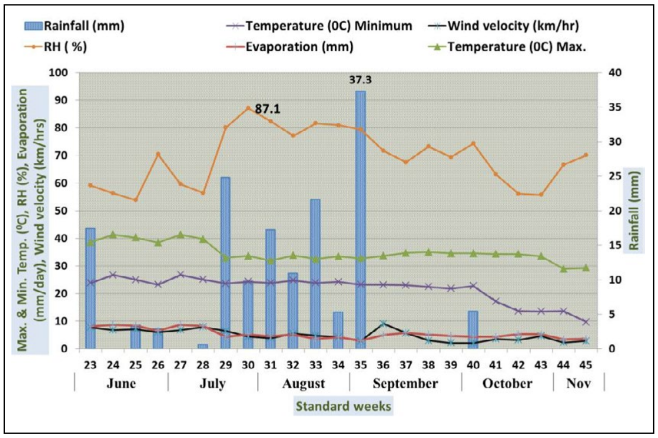

Figure 1: Mean weekly meteorological parameters during the crop growing period in *kharif* 2016

A composite soil sample at the depth of 0–15 cm was drawn from the experimental field for analysis before the beginning of the experiment. The soil was sandy clay loam (typical Ustochrept) in texture with medium organic carbon content, low available N and medium available P, and available K, and had a pH of 7.35 (Table 1).

2.2. Cropping history, experimental setup, and treatment details

The experimental field was under organic cultivation of a *Basmati* rice-wheat cropping system since 2003, with the fixed field layout and treatments. There were a total of sixteen treatments. One set of treatments was applied to rice only i.e. T_2-Farm yard manure (FYM) at 10 t ha^{-1}, T_3-*Sesbania* green manuring (SGM), T_4-SGM+blue green algae (BGA), T_5-SGM+FYM, T_6-SGM +FYM+BGA, a second set to wheat only viz., T_7-FYM at 10 t ha^{-1}, T_8-*Leucaena* green leaf manuring (LGLM), T_9-LGLM+*Azotobacter*, T_{10}-LGLM+FYM, T_{11}-LGLM+FYM+*Azotobacter*, and a third to both rice and wheat viz., T_{12}-FYM at 10 t ha^{-1} to rice and wheat, T_{13}-SGM for rice and LGLM for wheat, T_{14}-SGM+BGA for rice and LGLM+*Azotobacter* for wheat, T_{15}-SGM+FYM for rice and LGLM+FYM for wheat, T_{16}-SGM+FYM+BGA for rice and LGLM+FYM+*Azotobacter* for wheat and one T_1-absolute control. The culture of the BGA was obtained from the National Centre for Conservation and Utilization of Blue Green Algae, ICAR-IARI, New Delhi. BGA was applied at 2.5 kg ha^{-1} to the *Basmati* rice crop. Strains of *Azotobacter chroococcum* specific to wheat, obtained from the Division of Microbiology,

Table 1: Characteristics of the soil for the experimental field

Particulars	Value	Method
Mechanical composition		
1. Sand (%)	50.8	Hydrometer method (Bouyoucos, 1962)
2. Silt (%)	23.1	
3. Clay (%)	26.1	
4. Textural class	Sandy clay loam	
Physical properties		
1. Field capacity at 1/3 atmospheric tension (%)	24.7	Richards and Weaver (1943)
2. Bulk density (Mg m^{-3})	1.36	Chopra and Kanwar (1991)
Chemical composition		
1. pH (1:2.5; soil: water ratio)	7.35	Elico pH meter (Piper, 1950)
2. Electrical conductivity (dS m^{-1} at 25°C)	0.83	Solubridge method (Piper, 1950)
3. Organic C (%)	0.61	Walkley and Black (1934)
4. Available N (kg ha^{-1})	177.1	Subbiah and Asija (1956)
5. Available P (kg ha^{-1})	20.1	Olsen et al. (1954)
6. Available K (kg ha^{-1})	252.8	Jackson (1973)

ICAR-IARI, New Delhi, were used to inoculate the seeds according to the treatments. The chemical composition of nutrient concentrations in the organic sources of manure is given in Table 2.

2.3. Crop management

The applied treatments were tested on the 'Pusa *Basmati* 1' rice variety. It yields long grains with good aroma and excellent cooking qualities. The seedlings were raised for 25 days on beds of 10 m × 1 m prepared with a channel of 0.5 m between two beds for draining out extra water. *Sesbania* was incorporated in the main plot 58 days after sowing (DAS) with a tractor-drawn mould board plough followed by a heavy disc. Well-decomposed FYM was applied in the assigned plots. A 25-day-old healthy seedlings of the 'Pusa *Basmati* 1' variety were planted at 2–3 seedlings hill^{-1} at a spacing of 20×15 cm^2. Gap filling was done 7 days after transplanting (DAT) to maintain a uniform plant population in all the plots. BGA was applied 10 DAT in the assigned plot. Two manual hand weeding were carried out at 30 and 60 DAT to keep the plots free from weeds. Irrigation

Table 2: Chemical composition of organic manures

Parameters	FYM	*S. aculeata*	LGLM	BGA	*Azotobacter*
Weight (t ha^{-1})	10	5.48 (dry)	10 (fresh)	2.5 kg ha^{-1}	Seed treatment
N (%)	0.694	2.83	–	–	–
P (%)	0.263	0.34	–	–	–
K (%)	0.531	3.85	–	–	–
Total N applied (kg ha^{-1})	69.4	155.1	–	20	17
Total P applied (kg ha^{-1})	26.3	18.6	–	–	–
Total K applied (kg ha^{-1})	53.1	211.0	–	–	–

was started from the time of transplanting to maintain 3–5 cm standing water in the field. The subsequent irrigations were given as per the rainfall pattern and requirement of the crop and were fully ceased 10 days before harvesting of the crop.

2.4. *Sampling and observations*

2.4.1. *Biometrical observations*

Plant growth observations were recorded by selecting two rows (third from either side). Five random hills of rice plants were selected for recording biometrical observations.

2.4.1.1. *Plant height*

Five plants were selected randomly from each plot, and their height was measured at 30, 60, 90 DAT, and harvested from the ground level to the tip of the panicle. The average values were computed and expressed in cm.

2.4.1.2. *Number of tillers m^{-2}*

The total number of tillers of five random hills of rice was counted at 30, 60, 90 DAT, and harvest. The mean numbers of tillers m^{-2} were expressed as follows:

Tillers m^{-2}= Number of tillers $hill^{-1}$ × Number of hills in a m^2

2.4.1.3. *Leaf area and leaf area index (LAI)*

The fresh leaves were separated from the stem to measure the leaf area by using a leaf area meter (LI-COR Model L1-3000, Lambda Instrument Corporation, Nebraska, USA) and were expressed in cm^2 $plant^{-1}$.

LAI was calculated at 30, 60, and 90 DAT using the formula suggested by Evans (1972). LAI was expressed as the ratio of leaf surface area (1 side only) to the ground area occupied by the plant.

LAI=Total leaf area (cm^2)/Ground area (cm^2)

2.4.1.4. *Dry matter accumulation*

Five hills of rice were cut from ground level after random selection from each plot. These plants were sun-dried first and then oven-dried at 60–65°C till a constant weight was observed. The weight was recorded, and dry matter production ha^{-1} was calculated by using the following formula:

Dry matter production (t ha^{-1})=(Dry weight of plants of 5 hills×Number of hills in a ha/5)

2.4.2. *NPK, iron, manganese, zinc, and copper concentrations in rice grain and straw*

Grain and straw samples of rice were dried in a hot air oven at 60±2°C for eight hours and then ground in a Macro-Wiley Mill to pass through a forty mesh sieve. A 0.5 g grain and straw sample was taken as a representative sample for the determination of N, P, and K. The N concentration in grain and straw samples was determined by the modified Kjeldahl method (Jackson, 1973), total P by the Vanadomolybdo phosphoric acid yellow colour method, and K by the flame photometry method, as described by Prasad et al. (2006). The N, P, and K concentrations in grain and straw were expressed in percentages. Fe, Zn, Mn, and Cu were analyzed in a di-acid digest of rice grain and straw using AAS and were expressed in ppm or mg kg^{-1}.

2.4.3. *NPK and micronutrient uptake by rice grain and straw*

The uptake of NPK in grain and straw was calculated by multiplying their % concentrations by the corresponding yield. The total uptake was obtained by adding up their respective uptake in grain and straw. It was expressed in kg ha^{-1}. The micronutrients (Zn, Mn, Cu, and Fe) uptakes were estimated by multiplying their concentrations with the respective yield of grain and straw, and their uptake was reported in g ha^{-1}.

3. RESULTS AND DISCUSSION

3.1. *Growth parameters*

3.1.1. *Plant height*

The plant height of rice was significantly influenced by different organic manures, biofertilizers, and their combinations at all growth stages (Figure 2). At 30 DAT, the maximum plant height (66.0 cm) was recorded with T_{16} (SGM+FYM+BGA to rice and LGLM+FYM+*Azotobacter* to wheat), which was significantly higher than several treatments and superior to the control (T_1: 56.3 cm). Similar

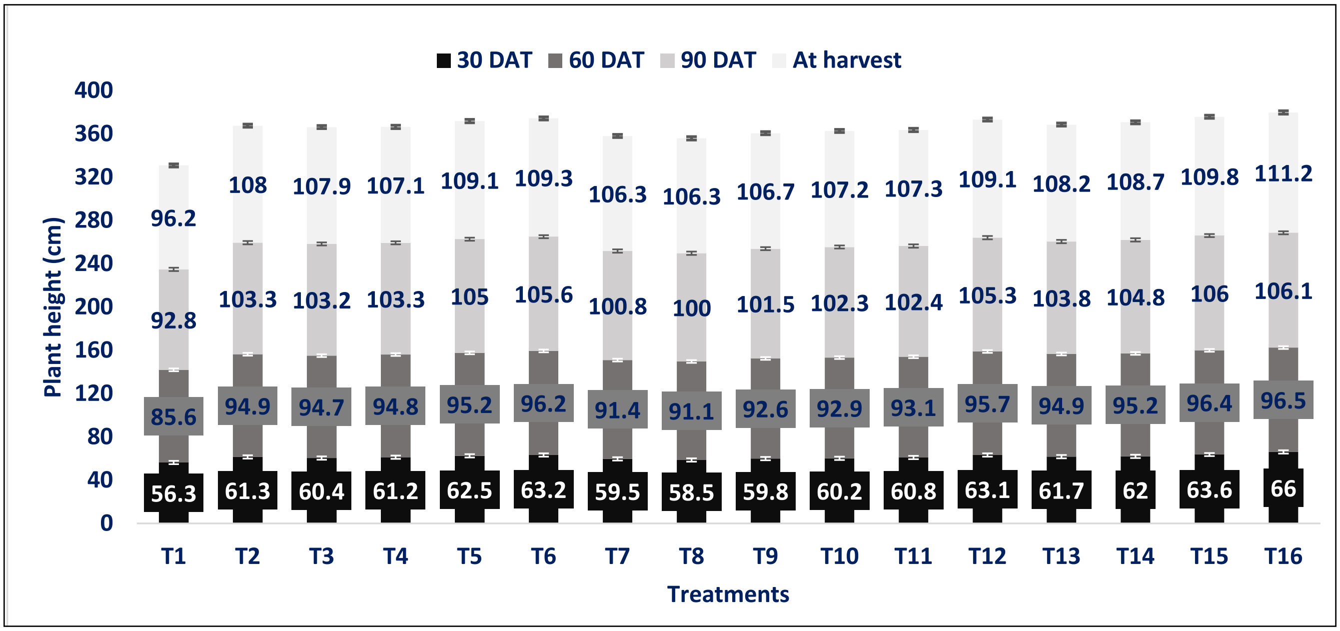

Figure 2: Plant height at 30, 60, 90, and harvest stage of *Basmati* rice; T_1: Absolute control; Applied only to rice; T_2: Farmyard manure (FYM); T_3: *Sesbania* green manuring (SGM); T_4: SGM+Blue green algae (BGA); T_5: FYM+SGM; T_6: FYM+SGM+BGA; Applied only to wheat; T_7: FYM; T_8: *Leucaena* green leaf manuring (LGLM); T_9: LGLM+*Azotobacter*; T_{10}: FYM+LGLM; T_{11}: FYM+LGLM+*Azotobacter*; Applied to both rice and wheat; T_{12}: FYM; T_{13}: SGM to rice LGLM to wheat; T_{14}: SGM+BGA to rice and LGLM+*Azotobacter* to wheat; T_{15}: FYM+SGM to rice and FYM+LGLM to wheat; T_{16}: FYM+SGM+BGA to rice and FYM+LGLM+*Azotobacter* to wheat; DAT*: Days after transplanting

trends continued at 60, 90 DAT, and at harvest, with T_{16} treatment maintaining the highest plant height, followed by T_{15} and T_6. Treatments applied only to rice (T_2–T_6) and to both crops (T_{12}–T_{16}) performed better than those applied to wheat only (T_7–T_{11}).

This consistent increase in plant height with T_{16} could be attributed to the synergistic effects of FYM, green manure, and biofertilizers applied to both current and previous crops, improving nutrient availability. The improved microbial activity and better soil health possibly enhanced nutrient mineralization and uptake, supporting the findings of Shanmugam and Veeraputhran (2001), Gangwar et al. (2004) and Shahane et al. (2019). Additionally, the slow-release of nutrients from FYM and nitrogen-fixing properties of GM and BGA might have contributed to sustained growth throughout the crop cycle, consistent with Mukherjee and Singh (2001) and Singh and Shivay (2019). Despite some statistical similarity among treatments, varietal traits might have played a role in reducing external treatment effects.

3.1.2. Number of tillers

The number of tillers m^{-2} increased significantly with application of various nutrient treatments (Table 3). At 30 DAT, T_{16} recorded the highest number of tillers (704.0 m^{-2}), significantly higher than the control (536.0 m^{-2}), and comparable to most other treatments. The trend of tiller numbers increased further at 60 DAT, with T_{16} again being the highest (724.4 m^{-2}). However, a natural decline was observed at 90 DAT and harvest due to competition and physiological senescence, with T_{16} still recording the highest effective tillers at harvest (568.5 m^{-2}), followed closely by T_{15} and T_6. The superiority of combined treatments like T_{16} and T_{15} confirms the enhanced tillering ability provided by sustained nutrient release and residual effects from previous crops. GM, especially *Sesbania*, used in rice along with biofertilizers and FYM, improved tillering significantly compared to their individual applications. These results were supported by Kumari et al. (2010), Singh et al. (2014), and Aulakh et al. (2016), who found better tillering in GM-treated plots. The low tiller count in treatments applied only to wheat, and the control likely reflects limited nutrient availability during early growth stages due to delayed mineralization.

3.1.3. Leaf area index (LAI)

The LAI values progressively increased from 30 DAT to 90 DAT across all treatments (Table 3). The highest LAI at all stages was recorded in T_{16}, peaking at 6.15 at 90 DAT, which was significantly superior to the control (3.97). Among the treatments applied only to rice, T_6 showed the highest LAI, while T_{11} was superior among wheat-only treatments.

Table 3: Effect of diversified nutrient sources on the number of tillers, leaf area index, and dry matter accumulation by organic *Basmati* rice

	Treatment	Tillers (Nos. m^{-2})				Leaf are index			Dry matter accumulation (g m^{-2})		
		30 DAT	60 DAT	90 DAT	E* At harvest	30 DAT**	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
T_1	Absolute control	536.0	545.0	465.0	430.6	1.49	3.07	3.97	214.6	426.7	936.6
Applied to rice only											
T_2	FYM	656.6	667.0	552.6	500.4	2.47	4.02	5.22	301.4	628.5	1256.8
T_3	SGM	649.6	662.0	539.6	488.8	2.14	3.73	4.89	306.2	611.7	1169.9
T_4	SGM+BGA	652.3	667.9	547.2	496.1	2.23	3.94	5.17	319.0	615.8	1197.9
T_5	SGM+FYM	681.6	695.0	589.5	522.0	2.73	4.88	5.48	359.9	655.2	1270.8
T_6	SGM+FYM+BGA	697.0	702.2	629.7	539.7	2.89	5.24	5.67	391.6	685.0	1291.6
Applied to wheat only											
T_7	FYM	579.9	585.9	509.3	453.8	1.6	3.34	4.51	246.5	525.0	1053.7
T_8	LGLM	568.0	577.0	501.4	443.9	1.56	3.33	4.49	246.3	519.0	1042.3
T_9	LGLM+*Azotobacter*	594.7	608.0	517.6	460.9	1.70	3.47	4.53	274.6	540.0	1084.1
T_{10}	LGLM+FYM	596.7	608.9	519.4	469.1	1.85	3.51	4.60	321.4	563.5	1132.6
T_{11}	LGLM+FYM+*Azotobacter*	647.7	652.9	531.7	479.3	2.04	3.60	4.77	293.7	591.7	1150.1
Applied to both crops											
T_{12}	FYM	680.6	692.0	607.8	526.9	2.78	5.09	5.57	362.7	663.3	1288.6
T_{13}	SGM to rice and LGLM to wheat	661.3	671.9	576.1	512.4	2.57	4.19	5.31	333.1	641.3	1269.0
T_{14}	SGM+BGA to rice and LGLM+ *Azotobacter* to wheat	672.0	678.9	586.4	519.1	2.64	4.35	5.43	350.3	641.8	1277.3
T_{15}	SGM+FYM to rice and LGLM+FYM to wheat	692.7	709.1	634.5	551.1	2.99	5.31	5.85	405.6	712.8	1313.5
T_{16}	SGM+FYM+BGA to rice and LGLM+FYM+*Azotobacter* to wheat	704.0	724.4	646.9	568.5	3.22	5.60	6.15	411.7	730.2	1350.3
	SEm±	16.24	16.86	14.13	11.94	0.037	0.075	0.168	6.46	13.4	25.17
	CD (p≤0.05)	46.91	48.7	40.82	34.47	0.106	0.217	0.484	18.66	38.69	72.69

E*: Effective number of tillers; DAT**: Days after transplanting

The higher LAI in T_{16} might be attributed to optimal canopy development due to nutrient synergy from FYM, GM, and biofertilizers. Treatments like T_6 and T_{15} also showed promising results, reaffirming the impact of integrated nutrient application on foliage expansion. The contribution of green manures in nitrogen availability through symbiotic fixation and decomposition further enhanced LAI, as per Mukherjee and Singh (2001) and Kumawat et al. (2024).

3.1.4. Dry matter accumulation

Dry matter accumulation (DMA) progressively increased with crop age, with the highest at 90 DAT (Table 3). Treatment T_{16} again recorded the highest DMA at all stages-411.7 g m^{-2} at 30 DAT, 730.2 g m^{-2} at 60 DAT, and 1350.3 g m^{-2} at 90 DAT-significantly superior to control and most other treatments. Treatments T_{15} and T_6 were statistically at par with T_{16} at several stages. The remarkable DMA in T_{16} could be attributed to the cumulative effects of enhanced photosynthetic surface (as indicated by LAI), nutrient availability, and balanced microbial population promoting decomposition and mineralization. Kumawat et al. (2023) also highlighted the role of organic nutrient management in maximizing biomass production in *Basmati* rice production. Furthermore, the continued application to both rice and the previous wheat crop ensured sustained nutrient availability, as supported by Dwivedi and Thakur (2000). This pattern aligned with increased LAI and plant height, confirming that biomass accumulation was positively influenced by vegetative vigor and nutrient synergy.

3.2. Macronutrient concentration in basmati rice *grain and straw and their uptake*

3.2.1. Nitrogen (N) concentration in grain and straw and its uptake

Treatment T_{16} (SGM+FYM+BGA to rice and LGLM+FYM+*Azotobacter* to wheat) exhibited significantly higher nitrogen concentration in grain (1.29%) and straw (0.58%) compared to the control and most other treatments (Figure 3a). This was followed by T_{15} and T_6 in their respective treatment categories. The highest N uptake by grain (67.6 kg ha^{-1}), straw (57.7 kg ha^{-1}), and total (125.3 kg ha^{-1}) was also recorded in T_{16} (Figure 3b), which was statistically superior to the control and many treatments, but on par with T_{15}, T_6, and other well-nourished combinations. The lowest total N uptake was recorded with the control (T_1, 58.4 kg ha^{-1}). The results aligned with findings by Quyen and Sharma (2003), Das et al. (2024), and Kumawat et al.

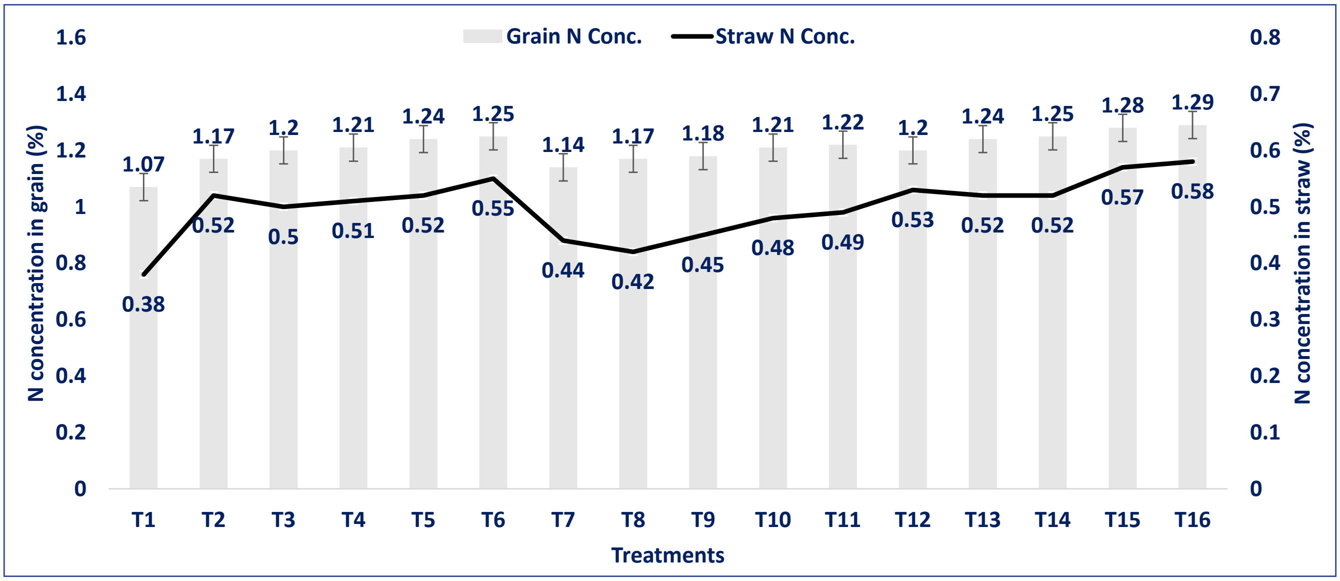

Figure 3a: Nitrogen concentration (%) in *Basmati* rice grain and straw

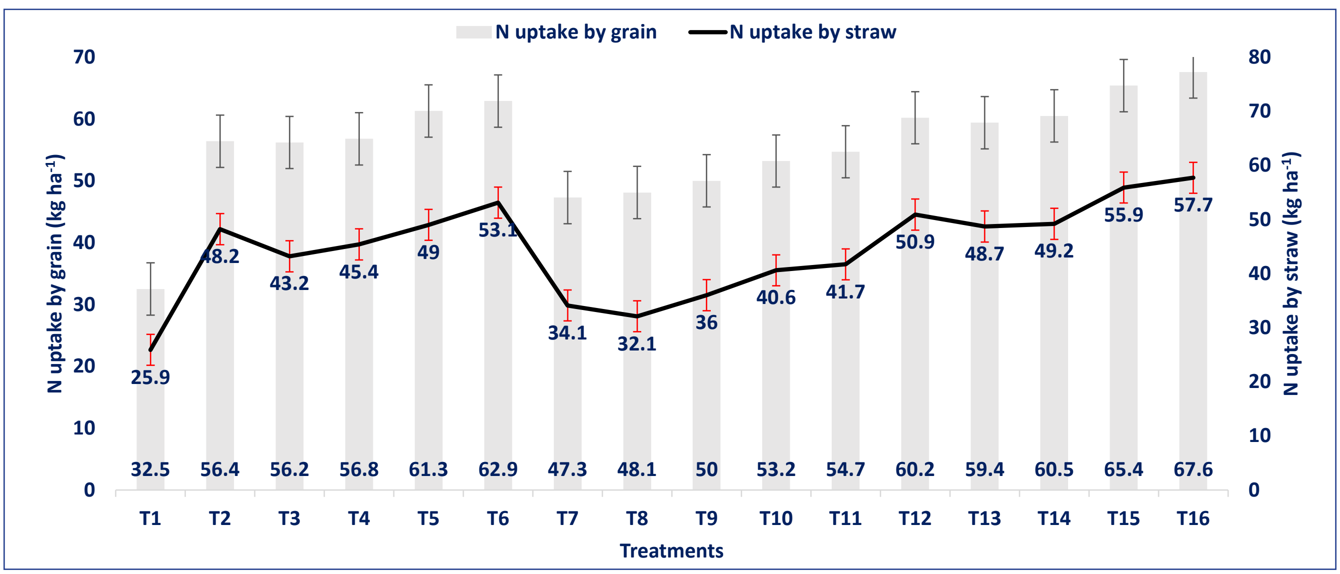

Figure 3b: Nitrogen uptake (g ha^{-1}) by *Basmati* rice grain and straw; T_1: Absolute control; Applied only to rice; T_2: Farmyard manure (FYM); T_3: *Sesbania* green manuring (SGM); T_4: SGM+Blue green algae (BGA); T_5: FYM+SGM; T_6: FYM+SGM+BGA; Applied only to wheat; T_7: FYM; T_8: *Leucaena* green leaf manuring (LGLM); T_9: LGLM+*Azotobacter*; T_{10}: FYM+LGLM; T_{11}: FYM+LGLM+*Azotobacter*; Applied to both rice and wheat; T_{12}: FYM; T_{13}: SGM to rice LGLM to wheat; T_{14}: SGM+BGA to rice and LGLM+*Azotobacter* to wheat; T_{15}: FYM+SGM to rice and FYM+LGLM to wheat; T_{16}: FYM+SGM+BGA to rice and FYM+LGLM+*Azotobacter* to wheat; DAT*: Days after transplanting

(2025), indicating the superior contribution of integrated green manure, farmyard manure, and biofertilizer treatments in enhancing N availability and uptake. Treatments applied to wheat only (T_7–T_{11}) showed comparatively lower values due to limited nutrient contribution to rice. FYM-treated plots recorded better total N uptake than GM alone, likely due to higher yield potential rather than increased nutrient concentration alone.

3.2.2. Phosphorus (P) concentration in grain and straw and its uptake

Similar to nitrogen, P concentration and uptake were also significantly enhanced by the integrated application of diversified organic nutrient sources in T_{16}. The highest grain P concentration (0.162%) and straw P concentration (0.079%) were observed in T_{16} (Table 4), closely followed by T_{15} and T_6. P uptake by grain (8.48 kg ha^{-1}), straw (7.88 kg ha^{-1}), and total (16.36 kg ha^{-1}) were also maximum under T_{16}, significantly higher than the control (7.22 kg ha^{-1} total uptake). As observed with N, treatments involving both rice and wheat nutrient applications outperformed rice- or wheat-only treatments. The consistent superiority of T_{16} and T_{15} across all parameters confirms the role of combined organic inputs in improving P availability. These findings agreed with those reported by Pooniya and Shivay (2013)

Table 4: Effect of diversified nutrient sources on phosphorus (P) and potassium (K) concentration and their uptake by organic *Basmati* rice grain, straw, and total

	Treatment	P concentration (%)		P uptake (kg ha^{-1})		Total P uptake (kg ha^{-1})	K concentration (%)		K uptake (kg ha^{-1})		Total K uptake (kg ha^{-1})
		Grain	Straw	Grain	Straw		Grain	Straw	Grain	Straw	
T_1	Absolute control	0.132	0.047	4.01	3.21	7.22	0.26	1.39	7.97	94.5	102.5
Applied to rice only											
T_2	FYM	0.149	0.059	7.14	5.49	12.64	0.32	1.48	15.27	138.2	153.5
T_3	SGM	0.147	0.056	6.89	4.85	11.74	0.32	1.45	14.74	126.1	140.8
T_4	SGM+BGA	0.146	0.057	6.87	5.04	11.91	0.32	1.47	14.95	130.9	145.8
T_5	SGM+FYM	0.152	0.063	7.53	5.99	13.52	0.32	1.50	16.03	141.2	157.2
T_6	SGM+FYM+BGA	0.152	0.068	7.70	6.51	14.21	0.33	1.51	16.62	145.2	161.8
Applied to wheat only											
T_7	FYM	0.141	0.051	5.83	3.98	9.81	0.31	1.44	12.68	113.0	125.6
T_8	LGLM	0.134	0.050	5.51	3.89	9.40	0.30	1.42	12.46	110.0	122.4
T_9	LGLM+*Azotobacter*	0.143	0.052	6.02	4.23	10.24	0.31	1.45	12.93	116.9	129.8
T_{10}	LGLM+FYM	0.140	0.053	6.14	4.44	10.58	0.31	1.46	13.75	122.7	136.5
T_{11}	LGLM+FYM+*Azotobacter*	0.145	0.054	6.51	4.58	11.09	0.31	1.47	14.04	125.4	139.5
Applied to both crops											
T_{12}	FYM	0.149	0.066	7.17	6.36	13.53	0.33	1.50	16.28	143.9	160.2
T_{13}	SGM to rice and LGLM to wheat	0.150	0.061	7.20	5.80	13.00	0.32	1.48	15.34	140.5	155.8
T_{14}	SGM+BGA to rice and LGLM+ *Azotobacter* to wheat	0.151	0.062	7.29	5.96	13.25	0.32	1.49	15.49	141.7	157.1
T_{15}	SGM+FYM to rice and LGLM+FYM to wheat	0.160	0.072	8.16	7.06	15.22	0.34	1.52	17.22	148.2	165.4
T_{16}	SGM+FYM+BGA to rice and LGLM+FYM+*Azotobacter* to wheat	0.162	0.079	8.48	7.88	16.36	0.34	1.52	17.86	151.6	169.5
	SEm±	0.002	0.001	0.179	0.142	0.238	0.002	0.01	0.32	3.05	3.07
	CD (p≤0.05)	0.005	0.003	0.516	0.41	0.687	0.005	0.03	0.92	8.8	8.87

E*: Effective number of tillers; DAT**: Days after transplanting and Kumawat et al. (2024), highlighting the impact of integrated organic management on P uptake in rice-based systems.

3.2.3. Potassium (K) concentration in basmati rice grain and straw and its uptake

Potassium concentration in grain and straw also followed a similar pattern. Treatment T_{16} recorded the highest K concentration in grain (0.34%) and straw (1.52%), along with the highest uptake in grain (17.86 kg ha^{-1}), straw (151.6 kg ha^{-1}), and total uptake (169.5 kg ha^{-1}). The values were statistically on par with T_{15}, T_6, T_{12}, and other nutrient-rich treatments but significantly higher than the control (T_1, 102.5 kg ha^{-1} total uptake). Among treatments applied to individual crops, T_6 (rice only) and T_{11} (wheat only) exhibited the highest K uptake. Treatments applied only to wheat (T_7–T_{11}) again showed relatively lower performance in K concentration and uptake in rice compared to rice-applied and combined treatments. This trend reinforced the view that nutrient application directly to rice was more effective for immediate crop uptake.

The higher K uptake associated with FYM treatments might be attributed to its sustained K-release pattern, supporting findings from Rathore et al. (1995), Dixit and Gupta (2000), and Srinivasarao (2023). GM+FYM combinations also enhanced K concentration and uptake as noted by Quyen and Sharma (2003).

3.3. Micronutrient concentration and its uptake by rice grain and straw

3.3.1. Iron (Fe) concentration in basmati rice grain and straw and its uptake

The concentration and uptake of iron (Fe) in rice grain and straw were significantly influenced by the application of diversified organic nutrient sources. The highest Fe concentration in grain (32.10 mg kg^{-1}) was observed under T_{16} (SGM+FYM+BGA to rice and LGLM+FYM+ *Azotobacter* to wheat), which was statistically at par with other treatments but significantly higher than the control (24.73 mg kg^{-1}). The corresponding highest Fe concentration in straw was also recorded with T_{16} (471.2 mg kg^{-1}), which was significantly superior to T_3, T_7, and the control (Figure 4a). Similarly, the uptake of Fe in grain and straw was highest under T_{16} (168.0 and 4,705.9 g ha^{-1}, respectively) (Figure 4b), resulting in the maximum total Fe uptake of 4,873.8 g ha^{-1} (Figure 4c). Among the category-wise treatments, T_6, T_{11}, and T_{16} recorded the highest Fe uptake under rice-only, wheat-only, and both crop applications, respectively.

The increased Fe uptake under T_{16} could be attributed to enhanced nutrient availability and improved plant growth resulting from the synergistic interaction of FYM, green manures, and biofertilizers. The combined effect of nutrient sources likely improved Fe solubility and uptake by plants, which was in agreement with the findings of Pooniya and Shivay (2013) and Kumawat et al. (2024).

3.3.2. Copper (Cu) concentration in basmati rice grain and straw and its uptake

Copper (Cu) concentration and uptake in *Basmati* rice grain and straw showed a significant response to organic nutrient treatments (Figure 5a,b). The maximum Cu concentration in grain (12.2 mg kg^{-1}) was recorded under T_{16}, followed by T_{15} and other integrated treatments, and was significantly higher than the control (8.6 mg kg^{-1}) (Figure 5a). Similarly,

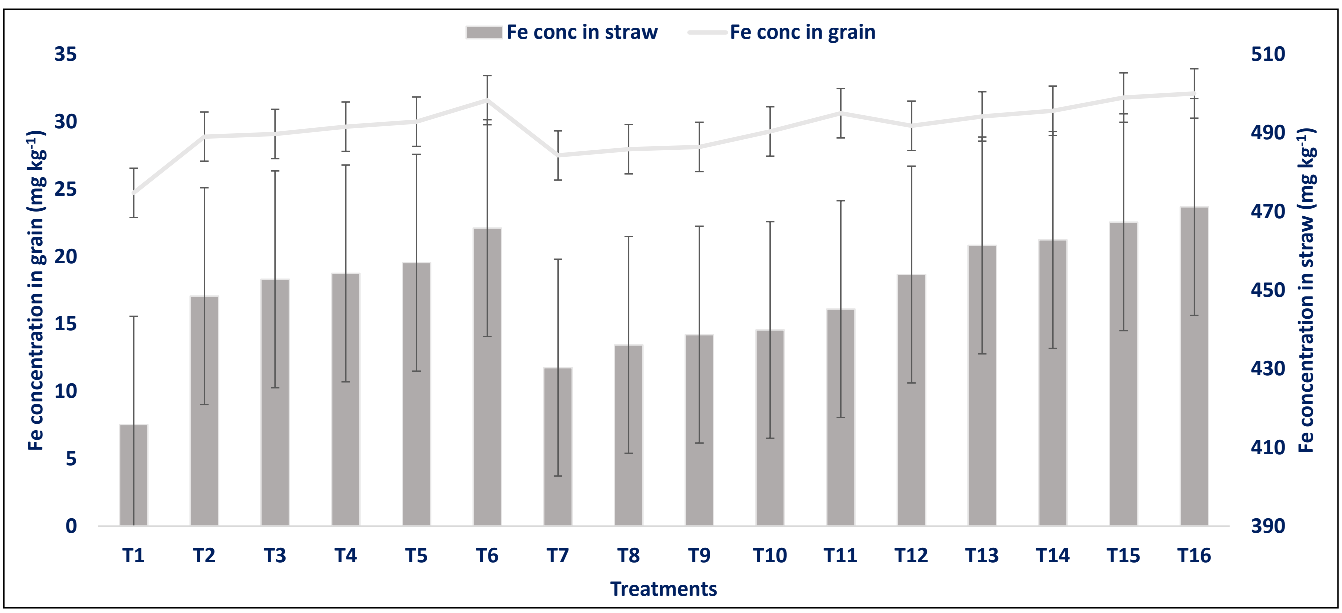

Figure 4a: Iron (Fe) concentration (mg kg^{-1}) in *Basmati* rice grain and straw

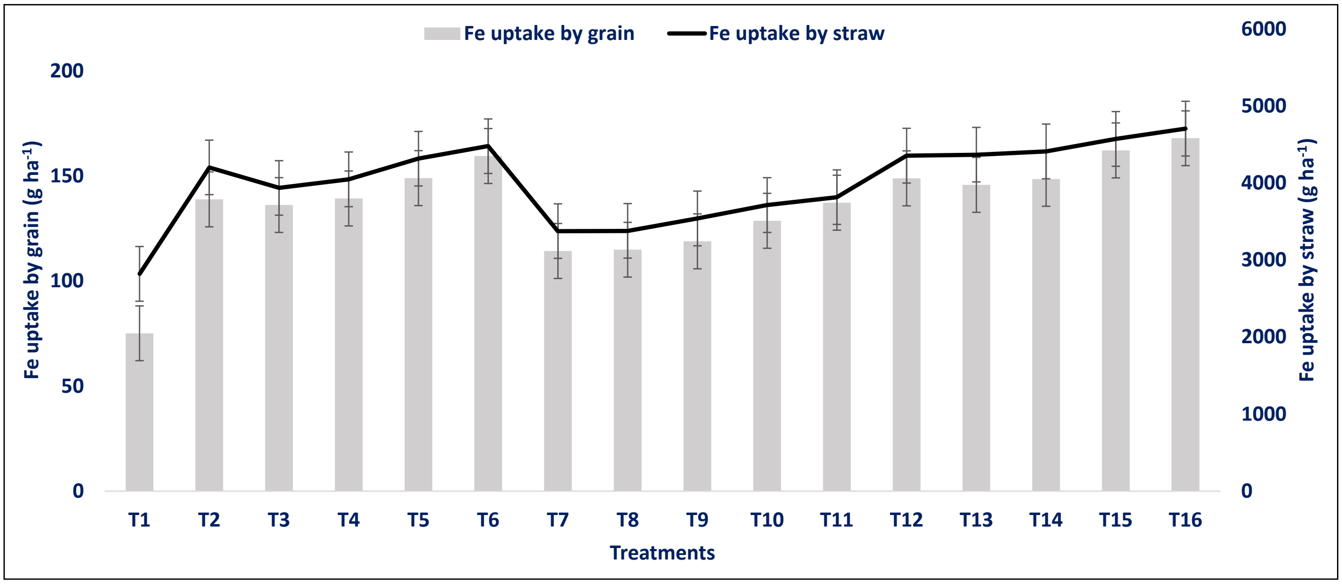

Figure 4b: Iron (Fe) uptake by *Basmati* rice grain and straw

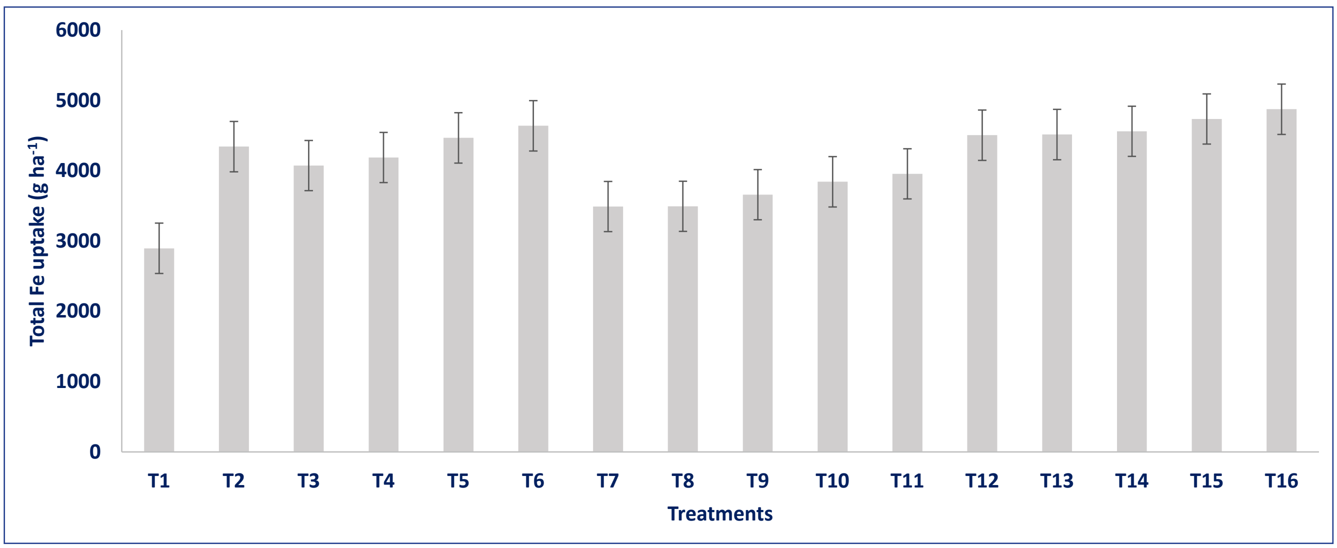

Figure 4c: Total iron (Fe) uptake by *Basmati* rice crop

Cu concentration in straw was highest in T_{16} (78.5 mg kg^{-1}) and lowest in the control (67.2 mg kg^{-1}) (Figure 5b). The Cu uptake followed a similar pattern, with T_{16} achieving the highest uptake in grain (63.6 g ha^{-1}) and straw (783.7 g ha^{-1}), leading to the maximum total Cu uptake of 847.3 g ha^{-1}. Treatments applied to both crops performed better than those applied only to rice or wheat. This enhanced Cu uptake was likely due to improved microbial activity, organic matter turnover, and enhanced Cu solubility in soil under organic management. The results were in line with earlier studies by Kumawat et al. (2024), which emphasized the benefits of organic amendments in micronutrient nutrition. The total Cu uptake by rice crop was recorded as the highest with T_{16} (847.4 g ha^{-1}), which was statistically on par with all other treatments except T_9, T_8, T_7, and T_1 (control). The lowest Cu uptake by the rice crop was noted with the control (482.3 g ha^{-1}) (Figure 5c).

3.3.3. Zinc (Zn) concentration in basmati rice grain and straw of rice and its uptake

The concentration and uptake of zinc (Zn) in rice grain and straw were markedly influenced by the organic nutrient treatments. The Zn concentration in grain was highest under T_{16} (34.8 mg kg^{-1}), significantly exceeding the control (26.8 mg kg^{-1}), while straw Zn concentration also peaked at T_{16} (172.3 mg kg^{-1}) (Table 5). Treatments T_6, T_{11}, and T_{16} recorded the highest Zn concentrations in rice applied organic nutrient sources-only, wheat applied organic nutrient sources-only, and both-crop application categories, respectively. Zn uptake in grain and straw

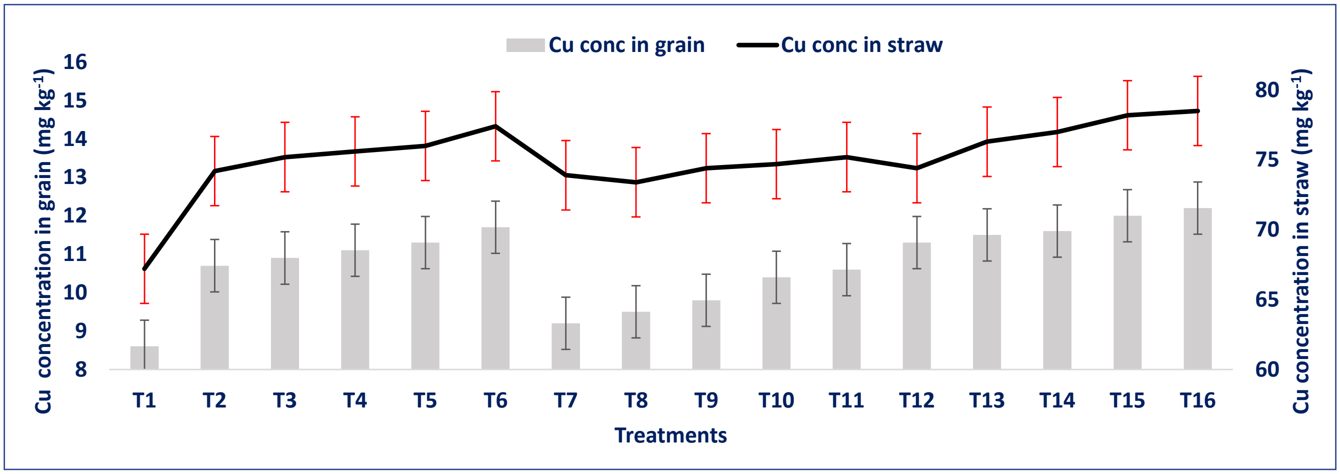

Figure 5a: Copper (Cu) concentration (mg kg^{-1}) in *Basmati* rice grain and straw

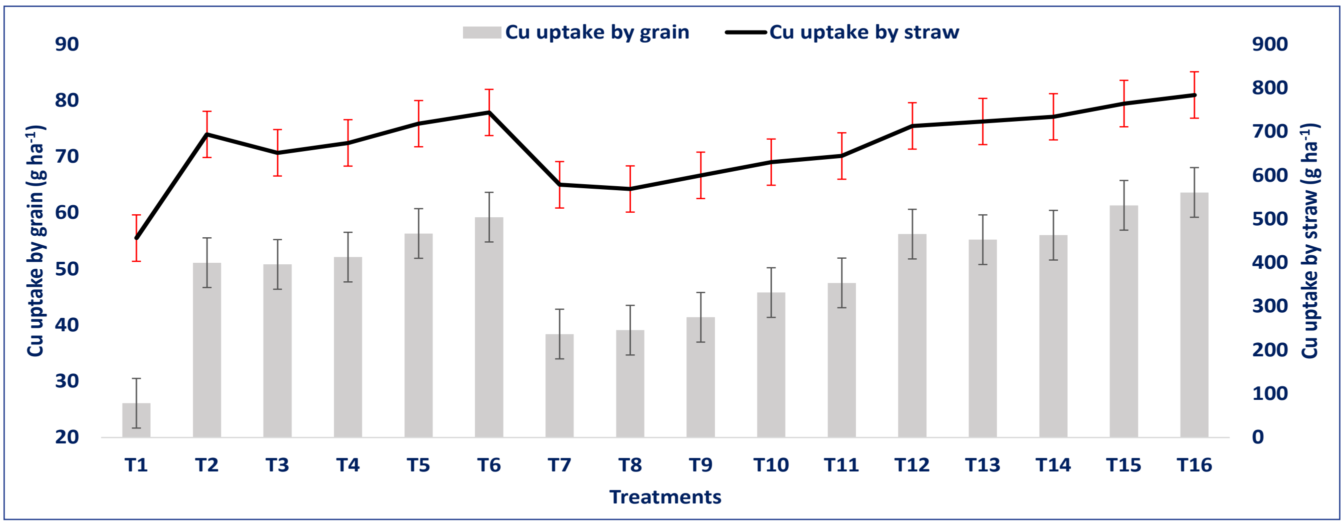

Figure 5b: Copper (Cu) uptake by *Basmati* rice grain and straw

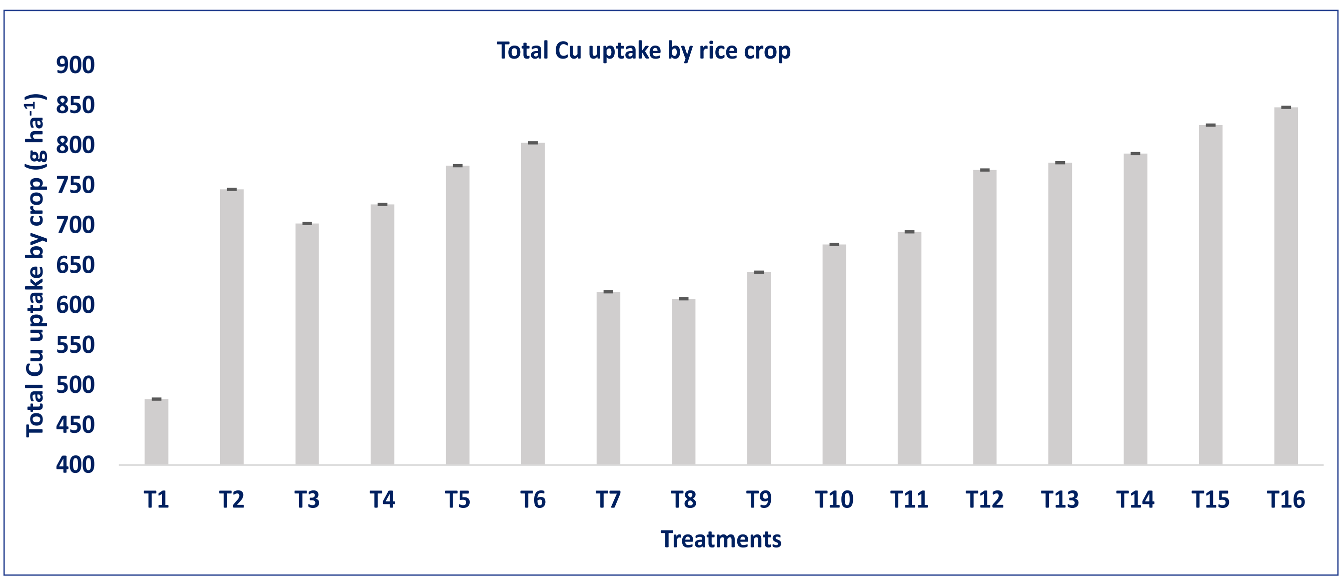

Figure 5c: Total copper uptake by *Basmati* rice crop

Table 5: Effect of diversified nutrient sources on zinc (Zn) and manganese (Mn) concentrations and their uptake by organic *Basmati* rice grain, straw, and total

	Treatment	Zn concentration (mg kg^{-1})		Zn uptake (g ha^{-1})		Total Zn uptake by rice crop (g ha^{-1})	Mn concentration (mg kg^{-1})		Mn uptake (g ha^{-1})		Total Mn uptake by rice crop (g ha^{-1})
		Grain	Straw	Grain	Straw		Grain	Straw	Grain	Straw	
T_1	Absolute control	26.8	158.3	81.4	1073.7	1155.2	27.7	112.1	84	760.3	844.3
Applied to rice only											
T_2	FYM	31.3	166.4	150.3	1559	1709.3	31.4	120.1	151	1124.8	1275.8
T_3	SGM	32.5	166.8	152.1	1450.2	1602.3	32.8	121.7	153.2	1057.7	1210.9
T_4	SGM+BGA	32.7	167.1	154	1486.5	1640.5	33.2	121.9	155.8	1085.3	1241.1
T_5	SGM+FYM	33.1	168.1	164.3	1588.6	1752.8	33.8	123.4	168.1	1165.4	1333.5
T_6	SGM+FYM+BGA	33.6	170.2	169.4	1636.5	1805.9	34.4	125.1	173.9	1203	1376.8
Applied to wheat only											
T_7	FYM	29.9	164.6	124	1290.2	1414.2	30.5	116.8	126.8	915.2	1042
T_8	LGLM	31.3	165	128.4	1275.3	1403.8	31.3	118.1	128.5	914	1042.4
T_9	LGLM+*Azotobacter*	31.6	165.5	132.8	1335.3	1468.1	32.1	118.6	135.7	957.4	1093.1
T_{10}	LGLM+FYM	32.4	166	142.3	1398	1540.3	32.9	119.2	144.7	1005.3	1150
T_{11}	LGLM+FYM+*Azotobacter*	32.7	168.4	146.4	1441	1587.4	33.2	119.4	148.8	1023.4	1172.2
Applied to both crops											
T_{12}	FYM	32.3	167.8	161.5	1609.6	1771.1	33.3	121.8	166.7	1168	1334.7
T_{13}	SGM to rice and LGLM to wheat	33.3	169.3	159.6	1601.8	1761.3	34.2	123.5	164.2	1168.6	1332.9
T_{14}	SGM+BGA to rice and LGLM +*Azotobacter* to wheat	33.7	171.1	162.5	1629.6	1792.1	34.5	123.8	166.3	1180.3	1346.5
T_{15}	SGM+FYM to rice and LGLM+FYM to wheat	34.4	171.8	175.7	1679.9	1855.6	35.1	125.4	178.8	1227.2	1406
T_{16}	SGM+FYM+BGA to rice and LGLM+FYM+*Azotobacter* to wheat	34.8	172.3	182	1720.2	1902.3	35.2	127.3	184.4	1271.5	1455.9
	SEm±	0.69	1.19	3.49	39.4	40.74	0.71	1.06	5.05	31.45	32.99
	CD ($p \leq 0.05$)	2.01	3.43	10.09	113.81	117.68	2.04	3.07	14.59	90.84	95.28

was also maximum under T_{16} (182.0 and 1,720.2 g ha^{-1}, respectively), resulting in the highest total Zn uptake of 1,902.3 g ha^{-1}. The superior Zn uptake can be attributed to increased Zn availability through organic acid production, microbial chelation, and better root proliferation stimulated by organic amendments and biofertilizers. The results supported earlier reports by Singh and Shivay (2019) and Kumawat et al. (2025), which showed enhanced Zn uptake under green manure-based nutrient management in an organic rice production system.

3.3.4. Manganese (Mn) concentration in basmati rice grain and straw and its uptake

The Mn concentration and uptake in rice grain and straw were significantly improved by organic nutrient management strategies (Table 5). Treatment T_{16} recorded the highest Mn concentration in grain (35.2 mg kg^{-1}) and straw (127.3 mg kg^{-1}), which was significantly superior to the control (27.7 and 112.1 mg kg^{-1}, respectively). The trend was consistent across treatment categories, with T_6, T_{11}, and T_{16} leading in their respective groups. Mn uptake in grain and straw was highest in T_{16} (184.4 and 1,271.5 g ha^{-1}, respectively), culminating in the maximum total Mn uptake of 1455.9 g ha^{-1}. The improvement in Mn uptake could be ascribed to increased microbial activity and organic matter that likely facilitated Mn mobilization and root absorption. The combined use of FYM, green manure, and biofertilizers improved soil conditions and plant nutrient acquisition, consistent with the findings of Pooniya and Shivay (2013) and Kumawat et al. (2025).

4. CONCLUSION

Integrated application of organic nutrient sources, specifically the combined use of *Sesbania* green manure, farmyard manure, blue green algae, *Leucaena* green leaf manure, and *Azotobacter*, significantly enhanced the plant height, tiller numbers, leaf area index, dry matter accumulation, and nutrient uptake, including NPK and micronutrients like Fe, Zn, Mn, and Cu in *Basmati* rice.

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