



Integrated Manure and Fertilizer Application: A Pathway to Enhanced Rice Yield and Soil Health

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Authors' contributions

This work was carried out in collaboration among all authors. All authors contributed equally in research activities as well as in manuscript preparation. All authors read and approved the final manuscript.

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ABSTRACT

A research study was carried out in the Soil Science field laboratory of Bangladesh Agricultural University, Mymensingh during the Aman season of 2021 to examine the effect of various manure and fertilizer combinations for optimizing the growth and yield of rice. The experiment employed a Randomized Complete Block Design (RCBD) with 3 replications across eight treatments. The treatment combinations were: T₁ (Control), T₂ (100% Recommended Fertilizer Dose (RFD)), T₃ (75% RFD + Cowdung (CD) @ 5 t ha⁻¹), T₄ (75% RFD + Poultry manure (PM) @ 3 t ha⁻¹), T₅ (75% RFD + Compost @ 5 t ha⁻¹), T₆ (75% RFD + Dhaincha Green Manure (GM) @ 10 t ha⁻¹), T₇ (50%

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RFD +CD @ 2.5 t ha⁻¹ + PM @ 1.5 t ha⁻¹) and T₈ (50% RFD + Compost @ 2.5 t ha⁻¹ + Dhaincha GM 5 t ha⁻¹). Statistical analysis conducted using R programming revealed that T₆ markedly improved growth metrics and yield-related traits, leading to a 12.2% rise in grain yield and a 13.24% rise in straw yield compared to T₂, where only chemical fertilizers were applied. This treatment also achieved the greatest macronutrient content and uptake, outperforming other treatments (T₃, T₄, and T₅) with equal nutrient amounts. Therefore, application of 75% recommended fertilizer dose along with dhaincha green manure (10 t ha⁻¹) offers a promising strategy for successfully cultivating BRRI dhan71 with a good soil health. This approach offers farmers a cost-effective method to boost productivity and support long-term soil fertility, and policymakers could promote it to enhance agricultural sustainability.

Keywords: Cowdung; poultry manure; dhaincha green manure; rice yield; BRRI dhan71.

1. INTRODUCTION

Rice serves as a primary dietary component for over half the global population and is cultivated in over a hundred nations, with Asia contributing to 90% of the worldwide yield [1]. Among the three rice seasons, T. Aman rice covers about 40.85% of the total rice area in Bangladesh [2]. Despite its extensive cultivation, rice yield has plateaued, falling short of its production potential, possibly due to imbalanced fertilizer application. The excessive or inappropriate use of chemical fertilizers significantly disrupts nutrient equilibrium in the soil, resulting in substantial nitrogen (N) losses. Specifically, N recovery rates are low (around 30%), and N use efficiency remains at approximately 35% in rice cultivation [3]. Furthermore, the use of chemical fertilizers detrimentally affects crop quality and leads to environmental issues like water contamination, greenhouse gas release, and nitrogen leaching [4].

Conversely, nutrients from organic fertilizers are released gradually over time, allowing for natural plant assimilation and avoiding the risks of over-fertilization, while also reducing soil acidity, supporting soil microorganisms, and enhancing soil structure for better air circulation and nutrient availability [5]. However, employing organic fertilizers without sufficient insight into their characteristics can lead to suboptimal yields or environmental harm due to incorrect application rates [6]. The lower nutrient concentration in organic fertilizers means that larger quantities are needed to effectively provide nutrients for plant growth. In consequence, the exclusion of inorganic fertilizers presents challenges for large-scale agriculture [7].

For sustainable agricultural practices that guarantee high-quality food production, it is essential to employ a balanced mix of organic

and inorganic nutrient sources. Reganold and colleagues (1990) emphasized the importance of this approach for enhancing the quality of agricultural output. Similarly, the proposal by Nambiar (1991) to integrate organic manures and chemical fertilizers is endorsed by Aktar et al. [8], indicating significant potential for stabilizing crop yields and enhancing soil fertility. Despite the known benefits, the optimal combination and application rates of manures and fertilizers remain elusive. This study seeks to illuminate this gap by focusing on BRRI dhan71. This study aimed to investigate the combined impact of manures and fertilizers on the yield and nutrient uptake of BRRI dhan71.

2. MATERIALS AND METHODS

2.1 Experimental Site and Soil

The research was conducted at the Soil Science Field Laboratory of Bangladesh Agricultural University, Mymensingh, located at 24.0°N, 90.0°E, during the Aman season of 2021. The soil, classified under the Sonatala series within the Agro-Ecological Zone (AEZ) of the Old Brahmaputra Floodplain, was characterized as silt loam.

Table 1. Chemical characteristics of initial soil

Characteristics	Value
pH (soil: water 1:2.5)	6.93
OC (%)	1.24
Total N (%)	0.1
Available P (ppm)	6.92
Exchangeable K (ppm)	6.77
Available S (ppm)	13.89
Available Zinc (ppm)	0.90
CEC (meq 100 g ⁻¹ soil)	15
EC (μS cm ⁻¹)	348

2.2 Experimental Design and Treatments

The present study utilized the modern, high-yielding T. Aman rice variety, BRR1 dhan71, developed by the Bangladesh Rice Research Institute (BRRI) in Gazipur. The experiment was laid out following a Randomized Complete Block Design (RCBD), with the experimental plot segmented into three blocks to serve as replications. A total of eight distinct treatments were applied including T₁ (Control), T₂ (100% Recommended Fertilizer Dose (RFD)), T₃ (75% RFD + Cowdung (CD) @ 5 t ha⁻¹), T₄ (75% RFD + Poultry manure (PM) @ 3 t ha⁻¹), T₅ (75% RFD + Compost @ 5 t ha⁻¹), T₆ (75% RFD + Dhaincha Green Manure (GM) @ 10 t ha⁻¹), T₇ (50% RFD + CD @ 2.5 t ha⁻¹ + PM @ 1.5 t ha⁻¹) and T₈ (50% RFD + Compost @ 2.5 t ha⁻¹ + Dhaincha GM 5 t ha⁻¹). Each experimental plot measured 4 m x 2.5 m, with 30 cm aisles separating them, and a 1 m wide drain delineating the blocks.

2.3 Collection of Different Manures and Their Chemical Composition

CD and PM were obtained from the dairy and poultry farms at Bangladesh Agricultural University, Mymensingh-2202. The materials underwent fermentation for 6 months (CD) and 1 month (PM) in piles before use. To prepare the compost for the experiment, these fermented materials were layered in a composting pit, with proper aeration and moisture levels maintained. The compost was regularly turned to enhance microbial activity and accelerate decomposition. After 3-4 months, the fully decomposed compost was sieved and used as a soil amendment in the field. Additionally, Dhaincha was collected from the Agronomy field at Bangladesh Agricultural University, Mymensingh-2202.

2.4 Crop Management

For Aman rice cultivation, the prescribed fertilizer rates consist of 90 kg N, 8 kg P, 50 kg K, 4 kg S, and 1 kg Zn per hectare. These doses were further adjusted according to various treatments. A week before transplanting, organic fertilizers were introduced into the soil. One day in advance of transplanting, the entirety of Triple

Super Phosphate (TSP), Muriate of Potash (MOP), Gypsum, and Zinc Sulphate doses were applied to the soil. Urea was strategically divided into three equal portions: urea was split thrice: 15 DAT (Day After Transplanting), 35 DAT (maximum tillering), and after 60 DAT (panicle initiation). Seedlings that had reached thirty days of age were attentively removed from the nursery bed and transplanted into the experimental plots. A spacing of 20 cm x 20 cm was maintained, with three seedlings carefully arranged in each hill. Essential intercultural practices, including timely moisture management and regular weeding, were conducted to maintain optimal growing conditions. The crop was fortunate to experience no significant insect pests or disease infestations throughout the cultivation period. Upon reaching full maturity, 1 m² was harvested from each plot, with the produce being individually bundled to facilitate precise yield assessment.

2.5 Data Collection on Plant Growth Parameters

Yield measurements were carefully conducted, with grain yield adjusted to a 14% moisture basis and straw yield evaluated based on sun-dried conditions. Data collection was conducted for each plot to ensure precision. Key yield components—plant height, panicle length, number of effective tillers per hill, grains per panicle, and 1000-grain weight.

2.6 Analysis of Soil Samples

The soil analysis at the beginning and end of the study involved assessing physical and chemical properties using established methods. Organic matter was determined by the Walkley and Black method [9], soil pH was measured at a 1:2.5 soil-water ratio using a glass electrode pH meter [10], total N was quantified by the semi-micro Kjeldahl method [11], available P was evaluated using the Olsen method [12], exchangeable K was assessed by Flame Photometry after extraction with 1N NH₄OAc at pH 7.0 [13], available S was determined by turbidity measurement in a spectrophotometer [14].

Table 2. Nutrient content of manures

Nutrient contents				
Manure	%N	%P	%K	%S
Cowdung	0.57	0.47	0.69	0.23
Compost	0.89	0.30	0.45	0.46
Poultry manure	1.18	1.13	0.81	0.35
Dhaicha GM	3.30	0.70	1.30	0.20

2.7 Analysis of Grain and Straw Samples

The grain and straw samples were analyzed for their N, P, K, and S contents adhering to standard laboratory procedures. To quantify the nutrient uptake by the grain and straw, the following formula was employed as per (Godebo et al.) [15]:

$$\text{Nutrient uptake (Kg ha}^{-1}\text{)} = \frac{\text{Nutrient content (\%)} \times \text{Yield (kg ha}^{-1}\text{)}}{100}$$

2.8 Statistical Analysis

The statistical analysis of the data involved an F-test to assess treatment effects. Subsequently, the Tukey HSD Test at a 5% level was employed to determine mean differences, with rankings indicated by letters. The data analysis was conducted using the R programming language.

3. RESULTS

3.1 Yield Contributing Characters of Rice

The application of both manures and chemical fertilizers had a marked effect on yield-

contributing factors of BRRI dhan71 (Fig. 1 and Appendix 1). T₆ displayed the tallest plants (111.58 cm) and the most effective tillers (14.22), with T₇ and T₄ exhibiting statistically equivalent performance. The control treatment yielded the shortest plants (82.45 cm) and the fewest effective tillers (8.01). Panicle length was greatest in T₆ (25.57 cm), with the control showing the least (18.96 cm). Similarly, T₆ produced the most grains per panicle (151.09), a count comparable to T₄ and T₇, while the control had the lowest (98.85). The 1000-grain weight was also highest in T₆ (24.20 g) compared to the control (21.90 g).

3.2 Yield Parameters of Rice

The integration of manures with fertilizers led to marked yield enhancements, as depicted in Fig. 2. and Appendix 2. Grain yield varied from 3.07 t ha⁻¹ in T₁ to 5.61 t ha⁻¹ in T₆. The results showed that T₆ achieved a 12.2% increase in grain yield and a 13.24% increase in straw yield compared to T₂, where only chemical fertilizers were applied. Additionally, yield was enhanced in T₆ compared to T₃, T₄, and T₅, which received similar amounts of chemical fertilizers.

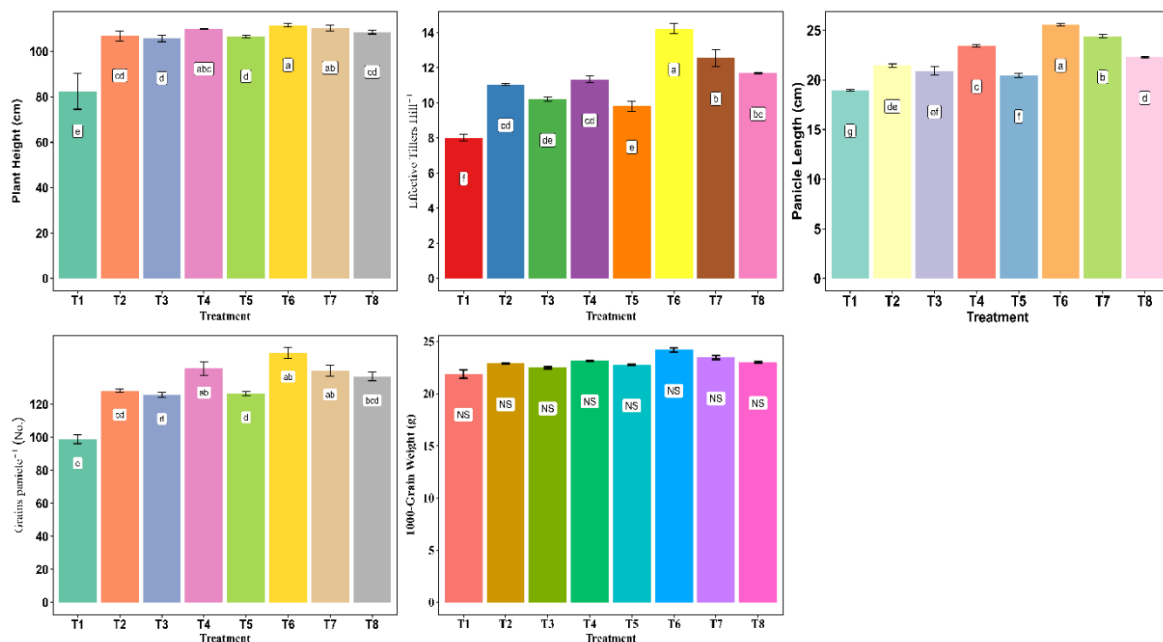


Fig. 1. Yield contributing characters of BRRI dhan71 as influenced by organic and inorganic fertilizers
(Data are mean±SE, n=3)

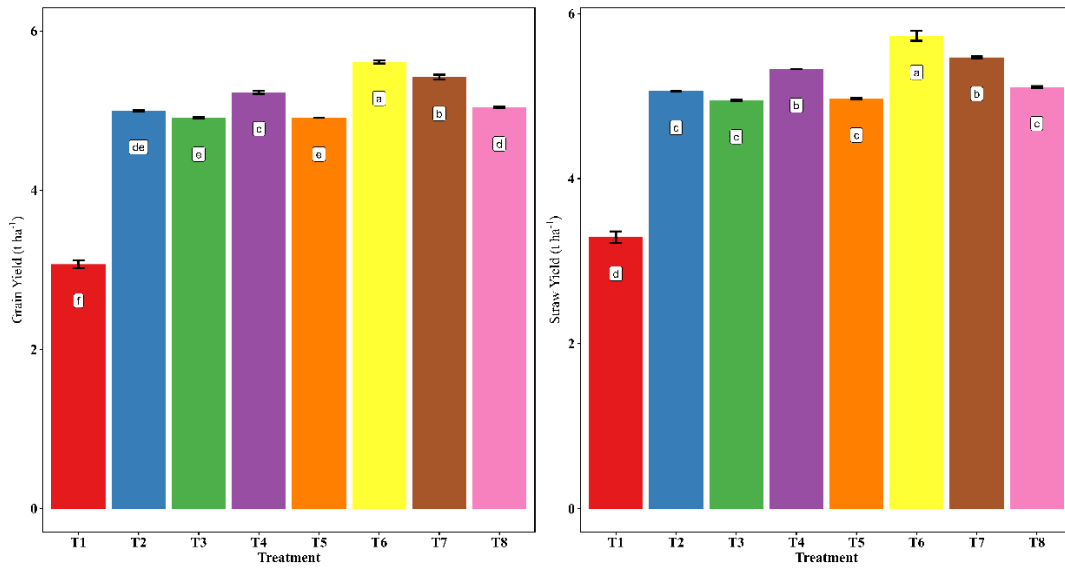


Fig. 2. Grain and straw yield variation in rice due to various treatment combinations
(Data are mean±SE, n=3).

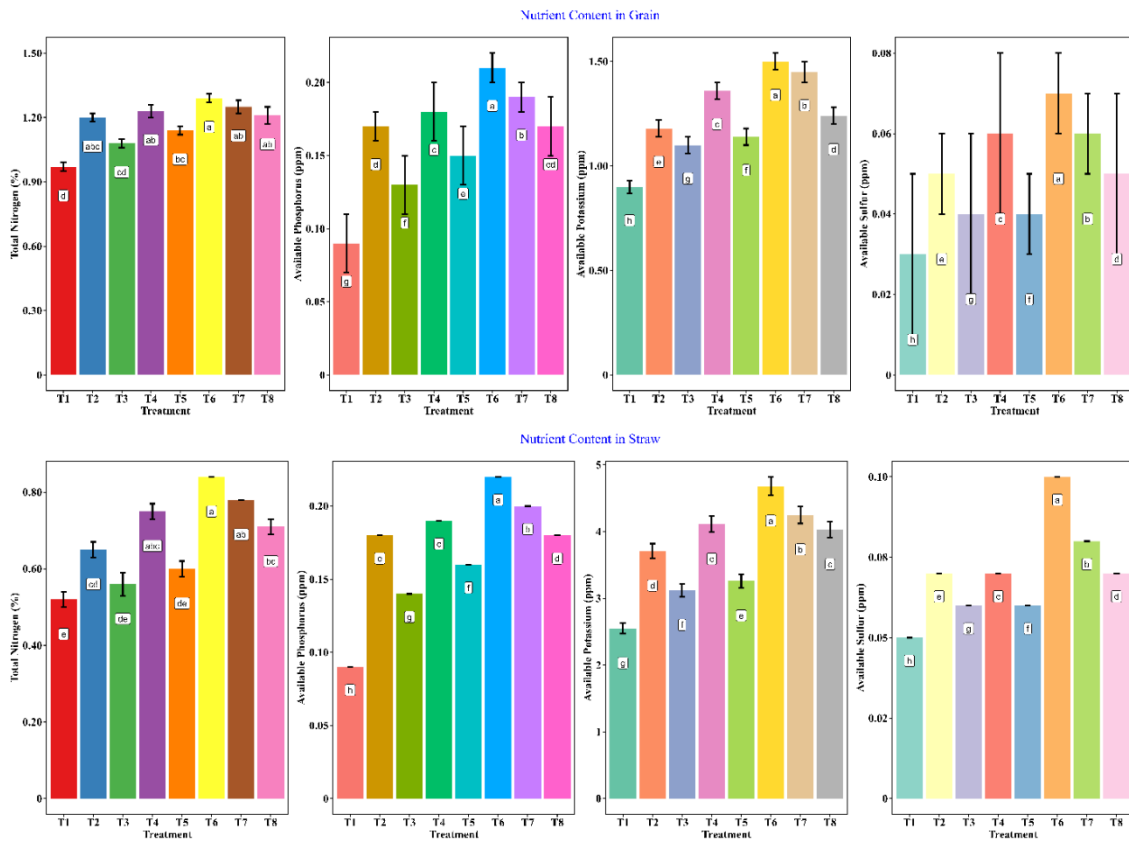


Fig. 3. Nutritional composition of rice grain and straw as affected by organic and inorganic fertilizers
(Data are mean±SE, n=3)

3.3 Nutritional Composition Grain and Straw

Both grain and straw nutrient levels of BRR1 dhan71 were significantly influenced by the simultaneous use of organic and inorganic fertilizers (Fig. 3). The grain exhibited N levels spanning from 0.97% to 1.29%, with the peak concentration found in T₆, which was comparable to treatments T₄, T₇, and T₈. Straw N level also peaked in T₆, ranging from 0.52% to 0.84%. P content saw a similar trend, with grain P between 0.09% and 0.21%, and straw P content from 0.09% to 0.22%, both highest in T₆. The amount of K in grain was notably higher in T₆ at 1.50%, with straw K content reaching up to 4.68%. Lastly, S content in the grain and straw of T₆ was the greatest, measuring at 0.07% and 0.10%, respectively.

3.4 Grain and Straw Nutrient Assimilation in Rice

The uptake of macronutrients by grain and straw of BRR1 dhan71 were significantly affected by various treatments (Fig. 4). Treatment T₆ consistently resulted in the highest nutrient uptake across all elements. Treatment T₆ resulted in peak nutrient absorption, with N levels reaching 62.19 kg ha⁻¹ in the grain and 16.69 kg ha⁻¹ in the straw. P assimilation was recorded at 10.33 kg ha⁻¹ for the grain, complemented by

4.37 kg ha⁻¹ in the straw. K uptake showed a notable rise, with grain and straw values at 72.39 kg ha⁻¹ and 93.77 kg ha⁻¹, respectively. Lastly, S uptake was measured at 1.99 kg ha⁻¹ for the grain and 1.91 kg ha⁻¹ for the straw. Conversely, the control treatment (T₁) exhibited minimal nutrient absorption. Notably, the uptake by straw was higher than that by grain for K, while grain uptake was more pronounced for N, P, and S.

3.5 Chemical Properties of Post-Harvest Soils

Significant variations in soil nutrient content were observed across treatments. N ranged from 0.09% in T₁ to 0.18% in T₆, a 20% increase over T₂, which only received chemical fertilizers. T₇ had the second-highest N content, showing a 13.33% increase over T₂, statistically identical to T₄. P content varied from 6.66 ppm (T₁) to 11.28 ppm (T₆), with T₆ displaying a 44.42% increase and T₇ showing a 33.31% increase over T₂, both similar to T₄. K ranged from 6.33 ppm in T₁ to 23.28 ppm in T₆, a 44.42% increase over T₂, followed by T₄ with 19.10 ppm, an 18.49% increase over T₂. S varied from 0.053 ppm (T₁) to 0.096 ppm (T₆), a 43.28% increase over T₂, with T₇ having the second-highest S content, also statistically similar to T₄. Overall, treatment T₆ significantly enhanced post-harvest soil nutrient levels compared to control and other treatments.

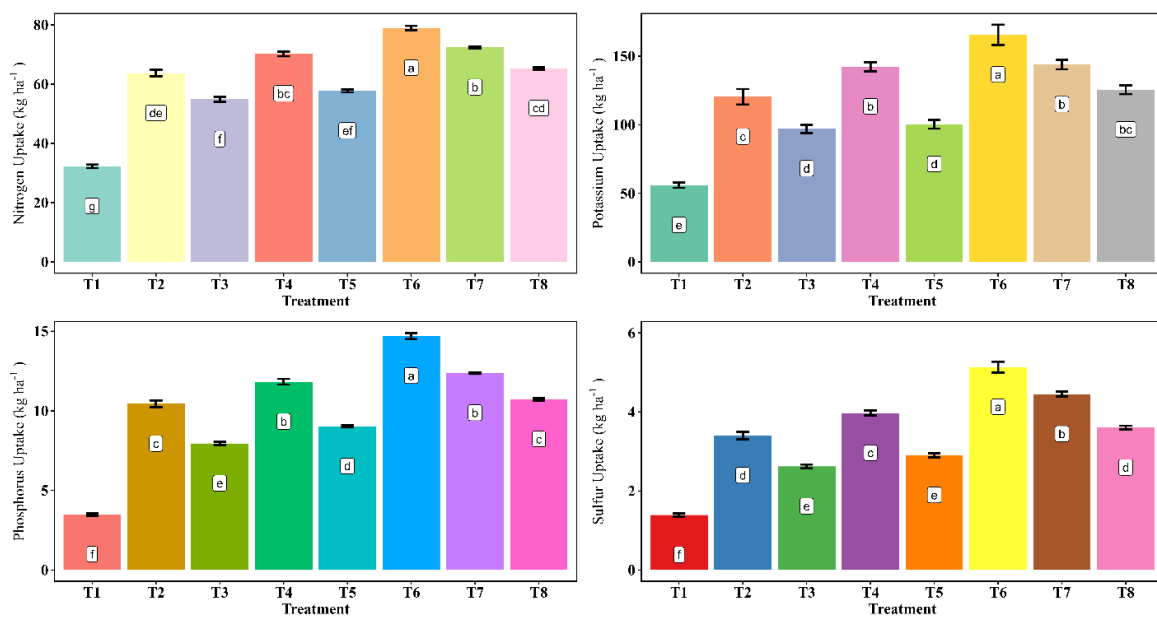


Fig. 4. Nutrient uptake in rice grain and straw influenced by organic and inorganic fertilizers (Data are mean ± SE, n=3)

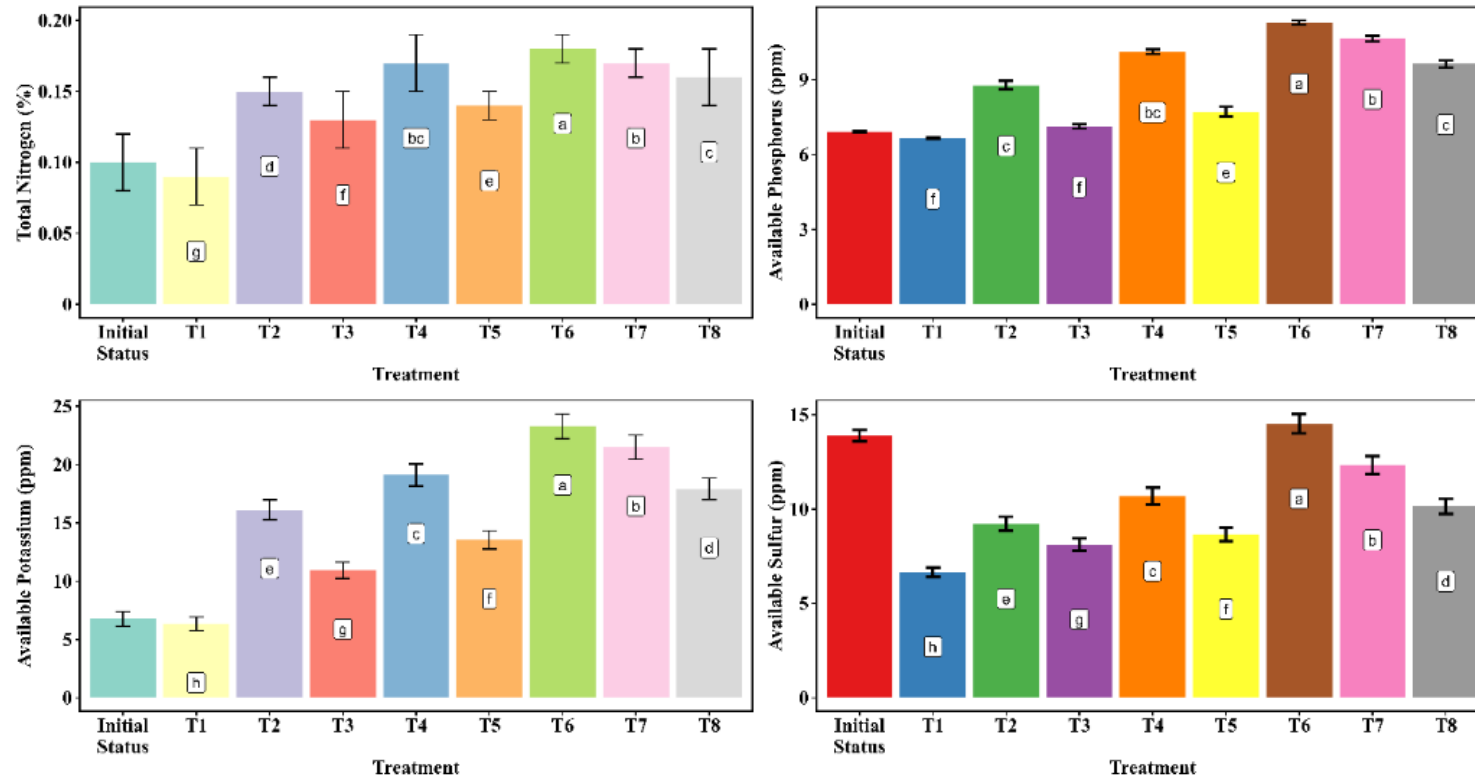


Fig. 5. Chemical properties of post-harvest soils
(Data are mean±SE, n=3)

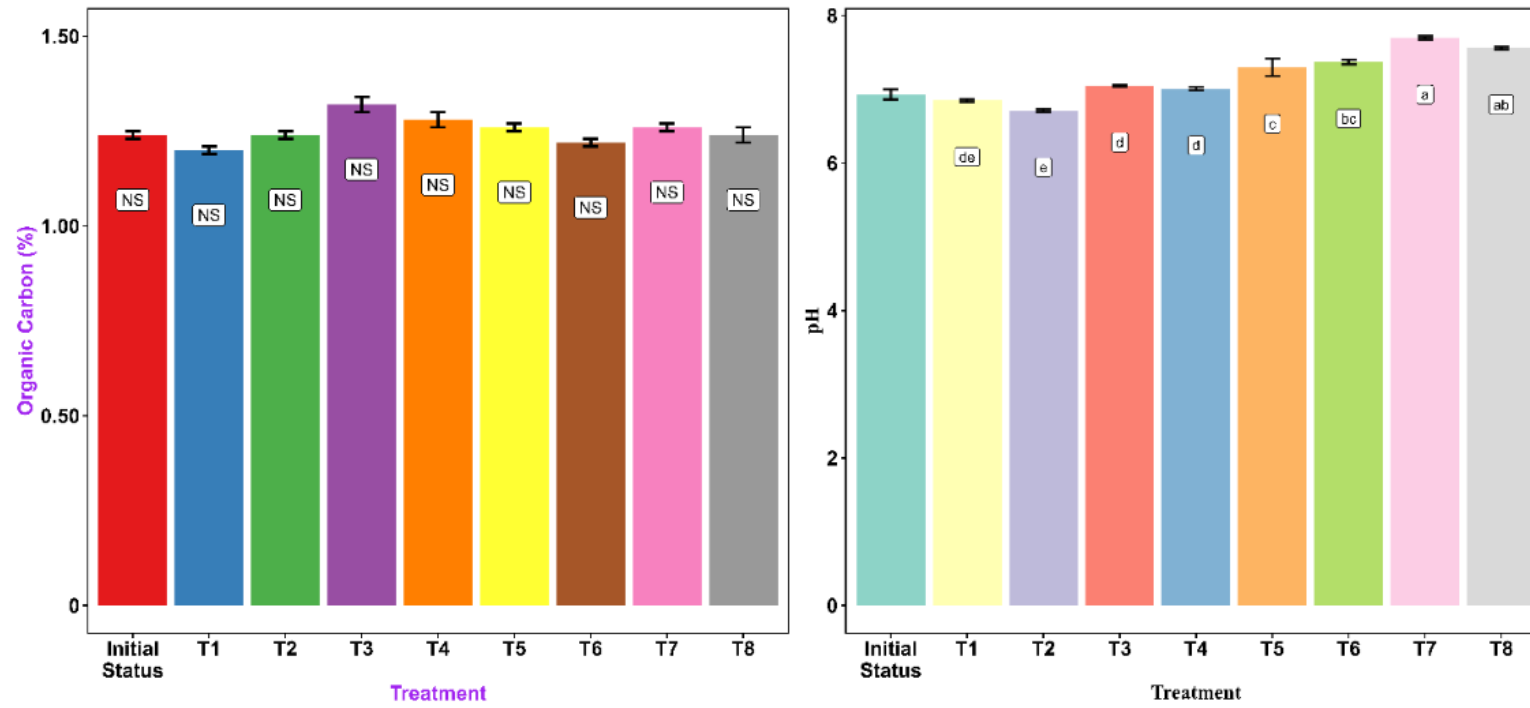


Fig. 6. Organic carbon and pH of post-harvest soils
(Data are mean±SE, n=3).

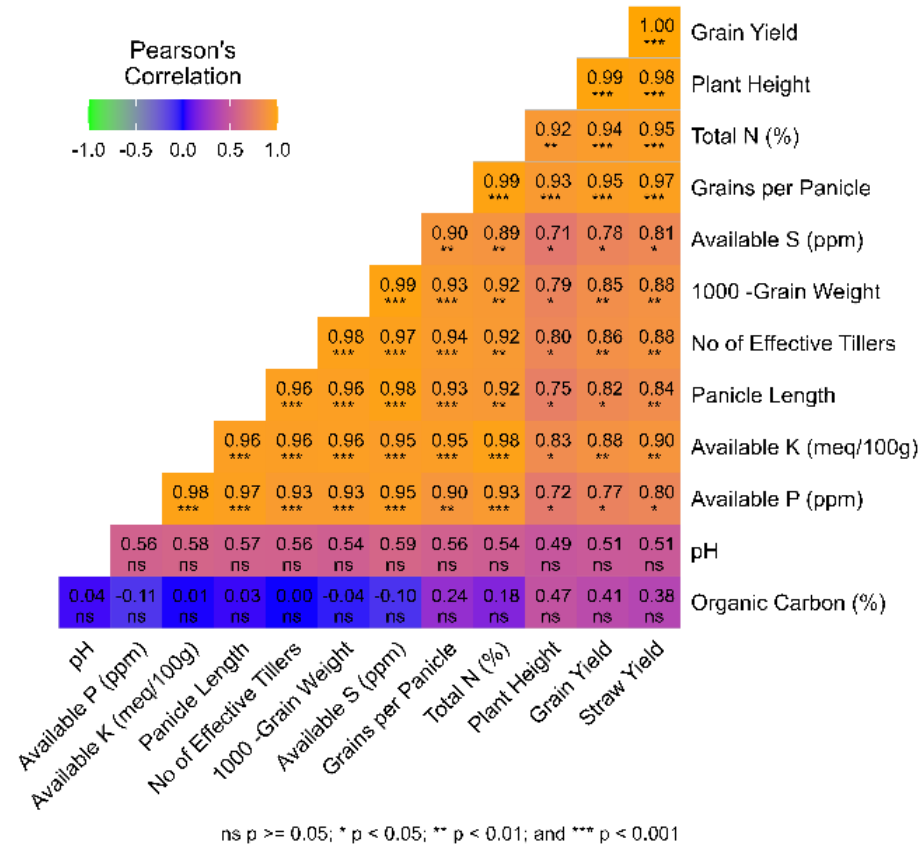


Fig. 7. Pearson's correlation between yield-contributing traits and soil chemical properties (Data are mean±SE, n=3)

3.5.1 Organic carbon and soil pH

The post-harvest soils exhibited a range of soil organic carbon (SOC) content, varying from 1.20% to 1.32% (Fig. 6). Among the treatments, T₃ had the highest SOC content at 1.32%, resulting in a significant 9.78% increase in total SOC compared to the control (T₁). Additionally, T₄ showed the second-highest SOC content (1.26%), contributing to a 6.52% increase in total SOC. Regarding pH, the post-harvest soils displayed a range from 6.71 to 7.70. Notably, T₇ exhibited the highest pH value of 7.70, while the lowest pH was observed in T₂.

3.6 Correlation Matrix among Growth Parameters, Yield Parameters, and Chemical Properties of Soil

The heatmap (Fig. 7) illustrates the Pearson correlation coefficients between various yield-contributing characters and soil chemical properties. The color gradient from green to red represents the correlation strength, with significant correlations marked by asterisks. Grain yield demonstrates a strong, statistically meaningful positive correlation with plant height, total N, and grains per panicle, indicating these factors are crucial in influencing yield. Other strong correlations include plant height with total N and panicle length. Conversely, soil pH exhibits weak or non-significant correlations with most variables, such as plant height and total N, suggesting a limited impact on yield components.

4. DISCUSSION

The experimental data showed a substantial enhancement in the yield-contributing traits of rice when subjected to synergistic utilization of manures and fertilizers, consistent with the findings of Liton Mia et al. [16] and Singh et al. [17]. This enhancement likely results from soil biochemical characteristics and microbial communities, enabling plant roots to better compete with nutrient loss mechanisms, as supported by Iqbal et al. [18]. The concurrent use did not significantly alter the 1000-grain weight, corroborating Moe et al. [3] suggesting that the factor influencing grain size remained unaffected, possibly due to genetic constraints or already optimal conditions. Additionally, the correlation heatmap revealed a strong positive correlation between the yield-contributing features and total N, which increased during integrated nutrient management. This highlights the pivotal role of

nitrogen in enhancing rice yield characteristics, as the increased total N likely facilitated better vegetative growth, tillering, grain formation, and grain filling, contributing significantly to the observed yield improvements consistent with Shrestha et al. [19]. Dhaincha GM, when combined with NPKS fertilizers, resulted in superior growth factors compared to other manures. This improvement may be attributed to the incorporation of green manures into the soil, which enhances soil N, P₂O₅, and K₂O content, along with increased mineralizable N, following the findings of Hlaing et al. [20].

The treatment T₆, which combined dhaincha GM with chemical fertilizers, yielded the highest grain and straw output. Previous research indicated that incorporating dhaincha with varying chemical fertilizer doses boosted rice grain yields by 32% to 77% over the control (Ehsan et al. [21]; Noor A-Jannat et al. [22]), while in India, GM application increased high-yielding rice varieties' yields from 0.65 to 3.1 t ha⁻¹ [23]. The observed enhancement likely results from increased total N in the soil, facilitated by GM crops' ability for nodule formation and N fixation. GM crops also contribute to higher organic matter production. These beneficial effects stem from the mineralization of soil nutrients derived from organic matter, aligning with Mahey et al. [24]. GM crops positively impact soil structure, texture, water-holding capacity, nutrient retention, plant fertilizer use, and microbial populations, as well as nitrogen (N) concentrations. These findings are consistent with the research of Hlaing et al. [20].

The synergistic interaction of manure and fertilizer notably affected the uptake of macronutrients viz. N, P, K, and S by the plants. These results encompass both the total nutrient uptake and their available forms in the soil, validating the findings of Kaiser et al. [25] and Khan et al. [26]. The increased nutrient uptake can be attributed to the enhanced nutrient availability from both the mineralization of organic matter and the immediate nutrient supply from fertilizers, which together improve the overall nutrient absorption efficiency of the rice plants. T₆ exhibited the highest NPKS content and uptake, significantly surpassing other treatments. This effect may be due to the lower C: N ratio in GM crops, resulting in higher mineralizable N. As a consequence, GM crops can enhance the content of N, P, and K, in accordance with Hlaing et al. [20].

5. CONCLUSION

The experimental findings underscore the benefits of integrating organic manures with chemical fertilizers, which significantly enhanced the growth and yield parameters of rice compared to the exclusive use of chemical fertilizers. Specifically, when used alongside chemical fertilizers (T₆), Dhaincha GM notably improved yield-contributing factors, as well as grain and straw yields of rice. Therefore, it can be recommended that T₆ can achieve maximum rice yield, effectively offsetting a 25% reduction in chemical fertilizers. Future research should explore the long-term effects of integrated nutrient management on soil health and crop sustainability, including impacts on soil nutrient dynamics and environmental outcomes over multiple growing seasons.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies have been used during the writing or editing of the manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

Appendix 1. Yield contributing characters of BRRI dhan71 as influenced by different treatments (Data are Mean±SE)

Treatment	Plant height (cm)	Effective tillers hill ⁻¹ (No.)	Panicle length (cm)	Grains panicle ⁻¹ (No.)	1000-grain weight (g)
T ₁	82.45±1.58e	8.01±0.20f	18.96±0.07g	98.85±2.61e	21.90±0.40
T ₂	106.92±0.45cd	11.05±0.05cd	21.44±0.20de	128.22±0.91cd	22.90±0.00
T ₃	105.75±0.28d	10.21±0.11de	20.90±0.43ef	125.76±1.40d	22.50±0.10
T ₄	109.88±0.03abc	11.33±0.19cd	23.44±0.15c	141.66±4.19ab	23.17±0.03
T ₅	106.60±0.10d	9.81±0.29e	20.44±0.20f	126.59±1.31d	22.77±0.03
T ₆	111.58±0.14a	14.22±0.29a	25.57±0.10a	151.09±3.22a	24.20±0.21
T ₇	110.36±0.25ab	12.56±0.48b	24.41±0.15b	140.41±3.46ab	23.47±0.18
T ₈	108.54±0.16bcd	11.69±0.03bc	22.31±0.07d	136.90±2.65bcd	23.00±0.06
CV%	1.00	3.55	1.41	3.39	1.05
Level of Significance	**	**	**	**	NS

** Significant at 1% level of probability, *Significant at 5% level of probability

Figure (s) having common letter (s) in a column do not differ significantly at 5 % level of significance by Tukey's HSD.

CV (%) = Coefficient of variation

Appendix 2. Integrated effect of manures and fertilizers on grain and straw yields of BRRI dhan71 (Data are Mean±SE)

Treatment	Grain yield (t ha ⁻¹)	Straw yield (t ha ⁻¹)
T ₁	3.07±0.05f	3.29±0.07d
T ₂	5.00±0.01de	5.06±0.00c
T ₃	4.91±0.01e	4.95±0.01c
T ₄	5.23±0.02c	5.33±0.00b
T ₅	4.91±0.00e	4.97±0.01c
T ₆	5.61±0.02a	5.73±0.06a
T ₇	5.42±0.03b	5.47±0.01b
T ₈	5.04±0.01d	5.11±0.01c
CV%	0.92	1.24
Level of Significance	**	**

** Significant at 1% level of probability, *Significant at 5% level of probability

Figure (s) having common letter (s) in a column do not differ significantly at 5 % level of significance by Tukey's HSD.

CV (%) = Coefficient of variation

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