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Integrated nutrient management influences the morpho-physiology and yield of aromatic fine rice under subtropical conditions

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Md. Rakhibul Hasan, Babli Rani Deb, Anjon Mallick, Anup Roy, Md. Abdur Rahman Sarkar, and Swapan Kumar Paul*

Department of Agronomy, Bangladesh Agricultural University, Mymensingh - 2202, Bangladesh

FINE RICE varieties are sensitive to nutrient management, which plays a crucial role in optimizing their yield and quality. This study aimed to evaluate the performance of selected fine rice varieties under different nutrient management practices. The experiment comprised four rice varieties *viz* Kalizira, Binadhan-13, BRRI dhan34 and BRRI dhan38 and five nutrient management *viz.* Control, recommended dose of urea (RDU) (150 kg N/ha), 50 % RDU, 50 % RDU + poultry manure (PM) 5 t/ha, 50 % RDU + PM 2.5 t/ha. The maximum grain yield (3.79 t/ha) was produced in BRRI dhan34 followed by Binadhan-13 and the lower one (3.05 t /ha) in BRRI dhan38. Integrated use of 50% RDU + PM 5 t/ha impacted significantly on morphological characteristics and yield-contributing traits of aromatic rice yield. Yield traits, such as effective tillers/hill, grains/panicle, and 1000-grain weight, exhibited the highest values when 50% of the RDU + PM 5 t/ha was applied whereas the control group had the lowest values. BRRI dhan34 fertilized with 50% RDU + PM 5 t/ha produced higher yield (3.79 t/ha) compared to other combinations. It can be concluded that at 50 % RDU + PM 5 t/ha can be used for the best performance in terms of grain yield of fine rice (cv. BRRI dhan34).

Keywords: Variety, nutrient management, morpho-physiology, rice production.

Introduction

Rice (*Oryza sativa* L.) is a key food source for nearly half of the global population and plays a crucial role in food security and rural livelihoods, especially in subtropical regions (Singh et al., 2020; El-Hity et al., 2024). Next to wheat it serves as a critical dietary staple and caloric source for nearly half the population in Asia. (Singh et al., 2020). Among the various types of rice, aromatic fine rice stands out due to its unique fragrance, superior grain quality, and high economic value (Roy et al., 2018; Laila et al., 2022). Fine rice is mostly utilized by people to make appetizing foods and is sold for more money in the market because of its unique aroma and acceptability. Bangladesh's chances of exporting these high-quality grains and making foreign cash are promising. Cultivating aromatic fine rice under subtropical conditions, however, presents several challenges, including nutrient management, which shows a critical part in influencing crop productivity.

Nitrogen is an essential nutrient required in greater quantities compared to other nutrients for optimal rice crop growth and yield (Djaman et al., 2018). The appropriate level of nitrogen is crucial for key physiological processes, including tillering, photosynthesis, vegetative development, biomass production, effective tillering, and spikelet development, ultimately enhancing rice productivity (Ferdush et al., 2020). In recent years, there has been growing interest in supplementing inorganic nitrogen with organic amendments such as poultry manure (PM), due to its potential to improve soil fertility and crop performance in a more sustainable manner. Poultry manure is a rich source of nitrogen and other essential nutrients, and its gradual nutrient release pattern makes it a valuable component in integrated nutrient strategies. The use of organic amendments like poultry manure not only enhances rice productivity by promoting accelerated phenology and improving the yield potential and quality of agricultural products but also helps in preserving soil integrity and restoring soil fertility (Nayak et al., 2020; Ali & Abdelaal, 2021). Integrated Nutrient Management (INM), which combines organic and

*Corresponding author email: skpaul@bau.edu.bd
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inorganic nutrient sources, has been recognized as a sustainable strategy to optimize crop production while maintaining soil health. INM has shown significant influence on rice production under various soil conditions across Bangladesh (Rahman et al., 2021). In this context, poultry manure, when used in combination with inorganic nitrogen, offers a balanced approach—providing an initial boost from the inorganic source and sustained nutrient availability from the organic component (Shaji et al., 2021). This strategy supports steady crop growth and enhances grain development. Therefore, in tropical regions, the judicious integration of organic amendments like poultry manure with mineral fertilizers is essential to optimize the morphological and physiological development and yield of rice crops (Esfahani et al., 2019; Paul et al., 2020). Notably, fine rice varieties often require lower input levels. Kabir et al. (2009) reported that the combined use of inorganic fertilizers with poultry manure at 2.5 t/ha could reduce nitrogen application by 31.25% without sacrificing yield. Furthermore, the joint application of organic and inorganic inputs improves soil physical properties and enhances nutrient uptake, leading to stable yields and mitigating potential deficiencies in secondary and micronutrients (Gill et al., 2014).

This experiment aimed to investigate the effects of rice variety and different rates of inorganic fertilizers in combination with poultry manure, and their integrated impact on the morphological and physiological traits, yield, and quality of aromatic fine rice.

Materials and Methods

Location and experimental set up

This research was carried out at the Agronomy Field Laboratory, Bangladesh Agricultural University (24°43′11.7″ N, 90°25′46.5″ E, 18m Elevation), Mymensingh, Bangladesh. The site is located in the Old Brahmaputra Floodplain (AEZ 9) and features non-calcareous dark grey floodplain soil (UNDP and FAO, 1988). The land was medium high with silty loam texture having pH 6.8, available N 0.13%, P 13.9 ppm, organic carbon 0.93%, K 16.3 ppm and low in organic matter content. The average temperature, relative humidity, rainfall and sunshine during experiment are shown in Figure 1. Four aromatic rice varieties namely Kalizira (a highly prized, short-grain aromatic rice known for its distinct flavor and cultural significance in Bangladesh), Binadhan-13, BRRI dhan34 and BRRI dhan38, and five nutrient managements *viz*. control (no inorganic and organic fertilizer), recommended dose of urea (RDU) 150kg /ha, 50% RDU, 50% RDU + PM 5 t/ha and 50% RDU + PM 2.5 t/ha. The experiment was organized using randomized complete block design and replicated thrice. The experiment included 60 plots with 4.0 m × 2.5 m size of each plot.

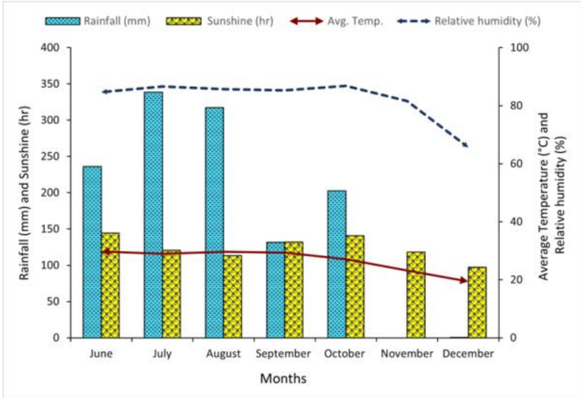

Fig. 1. Meteorological information of the experimental site

Management practices

Sprouted seeds of four varieties were broadcasted in a well-prepared seedbed with proper management practices. The field was prepared with a power tiller, followed by cross-ploughing with a traditional plough. The soil was later leveled using a ladder, and stubble and weeds were cleared. At final land preparation, P-K-S-Zn was applied @ 26-33-11-2 kg/ha, respectively in the form of TSP, MOP, Gypsum and $ZnSO_4$ and Respective amount of PM were applied as per treatment. At 15, 30, and 45 days after transplanting, urea was applied in three equal doses in accordance with treatment.

Growth Parameters

Bamboo sticks were used for marking five hills, excluding border rows, to collect data on plant height and tiller number at 15-day intervals starting on 30 Days after transplanting (DAT) and continuing until 90 DAT. For Leaf area index (LAI) measurements, five hills were sampled and harvested on each observation date, excluding the border rows and the central 1.0 m × 1.0 m area. An automatic leaf area meter was used to measure the LAI. According to Hunt (1978) and Yoshida (1981), LAI was computed as the sample's total leaf area divided by its entire ground area.

$$\text{LAI} = \frac{LA}{P}$$

Here, LA= Whole leaf area of all sampled plants leaf (cm^2), P= Total ground area covered by the plant (cm^2).

To measure total dry matter (TDM), five plants were collected for sampling from each plot at 15-day intervals up to 90 DAT. The plants were subsequently cleaned, roots were removed, and leaves were detached from the culms. The samples were dried in an electric oven at a constant temperature of 70°C for 72 hours. Each sample's weight was noted after drying. The crop growth rate (CGR) was calculated using the average data. The formula for determining CGR was mentioned below, as explained by Watson (1956).

$$CGR = \frac{1}{A} \times \frac{W_2 - W_1}{T_2 - T_1} \text{ g/m}^2 \text{ per day}$$

Here, W_1= TDM/hill at time T_1, W_2= TDM /hill at time T_2, A= Ground Area (m^2).

Harvesting and data collection

Five hills (without the border hills) were arbitrarily chosen at full maturity from every plot and uprooted to record necessary data related to crop characters and yield components. Central 1.0 m × 1.0 m area from each plot was harvested, properly wrapped, tagged, and thoroughly threshed. Grains were sun-dried to a moisture content of 14%, and straws were properly dried and converted to tons per hectare (t/ha). Harvest index (%) was calculated with the following formula:

$$Harvest\ index\ (\%) = \frac{Grain\ yield}{Biological\ Yield} \times 100$$

Statistical Analysis

Collected datasets were tabulated and statistical analysis was done using a computer program MSTAT. The mean variances were determined by DMRT using the ANOVA technique (Gomez and Gomez 1984).

Results

The interaction between variety and nutrient management significantly affected plant height, tillers/hill, LAI, TDM and CGR (Table 1). Plant height sharply raised irrespective of treatments and significantly rose to 60 DAT. At 60 DAT, the interaction of BRRI dhan34 with 50% RDU + PM at 5 t/ha (V_3×T_4) produced maximum plant height (98.90 cm) where the minimum plant height (80.53 cm) was recorded in BRRI dhan38 with control treatment (V_4×T_1) interaction (Table 1). Irrespective of treatments tillers/hill and LAI increased up to 75 DAT and thereafter abject. The results revealed that at 75 DATs BRRI dhan34 with 50% RDU + PM at 5 t/ha (V_3×T_4) produced maximum (16.87) tillers/hills which was at par with V_3×T_2 (BRRI dhan34 with RDU 150 kg /ha), V_1×T_4 (Kalizira with 50% RDU + PM 5 t/ha) and V_1×T_2 (Kalizira with RDU 150 kg /ha) while the lowest one (13.3) was observed in V_4×T_1 (BRRI dhan38 with control treatment) (Table 1).

The highest LAI was found in V_3×T_4 (BRRI dhan34 with 50% RDU + PM at 5 t/ha) which was as good as V_3×T_5 (BRRI dhan34 with 50% RDU + PM 2.5 t/ha), V_3×T_2 (BRRI dhan34 with RDU 150 kg /ha), V_1×T_4 (Kalizira with 50% RDU + PM 5 t/ha) and V_1×T_2 (Kalizira with RDU 150 kg /ha) but the lowest one (4.14) was documented in V_4×T_1 (BRRI dhan38 with control with no manure and fertilizer). At the last measurement date 90 DATs the highest TDM (51.27 g /hill) was achieved from V_3×T_4 (BRRI dhan34 with 50% RDU + PM at 5 t/ha) followed by V_3×T_5 and minimum (25.77 g/hill) was recorded in V_2×T_1 (Binadhan-13 with control treatment) at 90 DAT (Table 2). CGR sharply increased up to 60-75 DAT then declined. The highest CGR (4.533 g/cm^2 per day) was seen in V_3×T_2 (BRRI dhan34 with RDU 150 kg /ha) followed by V_3×T_4 at 60-75 DAT. CGR was the lowest in Kalizira with 50% RDU + PM 5 t/ha (V_1×T_4) (1.48 g/cm2 per day) between 60-75 DATs (Table 3).

The interaction exhibited a considerable outcome on effective and non-effective tillers/hill (Table 4). V_3×T_4 (BRRI dhan34 with 50% RDU + PM at 5 t/ha) resulted the maximum effective tillers/hill (12.67) which was at par with V_3×T_2, V_2×T_4 and V_1×T_4 while minimum effective tillers/hill (5.33) was noticed in V_4×T_1 (Table 4). The maximum non-effective tillers /hill (4.00) was in the interaction V_3×T_1 followed by V_4×T_2 and least non-effective tillers /hill (0.57) was observed in V_3×T_5 (BRRI dhan34 × 50% RDU + PM 2.5 t/ha). A statistically significant interaction was observed between variety and nutrient management for panicle length, grains per panicle, and sterile spikelets per panicle (Table 4). V_3×T_4 (BRRI dhan34 with 50% RDU + PM at 5 t/ha) had the longest panicle (27.40 cm), which was statistically comparable to V_3×T_5, while V_4×T_1 had the smallest panicle length (20.67 cm). The highest grains/panicle (139.3) was attained from V_3×T_4 which was at par with other treatment combinations except V_2×T_1 and V_4×T_1 (lowest value 114.7). Where the maximum sterile spikelets/panicle (27.00) was spotted in V_3×T_4 which was at par with V_3×T_3, V_3×T_2 and V_1×T_4, and the minimum sterile spikelets/panicle (7.63) was obtained in V_4×T_1 (BRRI dhan38 × no fertilizer and manure).

Table 1. Interaction effect of variety with nutrient management on plant height and total tillers per hill in aromatic fine rice.

Interaction (Variety × Nutrient management)	Plant height (cm)					Tillers/hill (no)				
	DAT					DAT				
	30	45	60	75	90	30	45	60	75	90
$V_1 \times T_1$	42.77	63.63h-k	87.63cde	97.80	107.3	4.20f-i	7.76cde	9.19gh	13.70fg	12.27d
$V_1 \times T_2$	44.33	67.73fgh	88.20cd	98.70	111.5	4.63efg	7.933b-e	9.50g	16.07abc	12.73cd
$V_1 \times T_3$	43.00	65.67f-i	88.0cd	98.33	111.0	4.30efg	7.80cde	9.43g	14.13efg	12.37 d
$V_1 \times T_4$	43.83	68.87efg	89.00cd	99.33	112.8	4.63efg	8.06bcd	9.76g	16.64ab	12.97cd
$V_1 \times T_5$	43.33	68.30e-h	88.67cd	98.33	112.3	4.34efg	8.00bcd	9.60g	14.67def	12.57 d
$V_2 \times T_1$	41.00	62.27ijk	87.07cde	98.37	103.8	3.50ij	6.53fg	6.74j	13.37 g	12.20 d
$V_2 \times T_2$	45.13	64.70g-j	87.77cde	99.10	107.4	5.03 de	7.66de	13.40d	13.5 g	15.20 b
$V_2 \times T_3$	42.77	64.4gh-k	85.3def	97.17	107.1	4.40efg	6.56fg	11.83f	13.63fg	12.8 cd
$V_2 \times T_4$	48.67	84.30ab	97.23ab	105.2	116.2	5.80bc	8.60b	14.20c	15.37cd	16.00ab
$V_2 \times T_5$	47.10	75.00d	95.07ab	104.5	115.3	5.76bc	7.80cde	12.37ef	13.73fg	15.33ab
$V_3 \times T_1$	43.33	70.17ef	88.37cd	98.57	110.6	4.96def	7.80cde	9.40g	15.07cde	13.63c
$V_3 \times T_2$	47.30	77.13cd	94.70ab	103.6	117.3	5.54cd	7.97bcd	15.17ab	16.70ab	16.26a
$V_3 \times T_3$	43.90	72.80de	91.90bc	102.5	111.7	4.96def	8.53bc	12.4 e	15.70bc	15.17b
$V_3 \times T_4$	49.73	87.03a	98.90a	112.0	120.3	7.22a	9.76a	15.50a	16.87a	16.33a
$V_3 \times T_5$	48.00	81.17bc	95.70ab	107.1	117.3	6.26b	8.36bcd	14.90b	16.00abc	15.87ab
$V_4 \times T_1$	40.67	59.47k	80.53f	93.90	102.4	3.37j	6.35g	7.527i	13.3g	12.10d
$V_4 \times T_2$	43.10	62.40ijk	82.23ef	95.17	104.6	3.50hij	6.80fg	8.033i	14.33efg	12.40d
$V_4 \times T_3$	41.67	60.13jk	81.2f	94.47	104.3	3.46ij	6.46fg	7.833i	13.83fg	12.33d
$V_4 \times T_4$	43.47	64.77g-j	83.87def	95.30	105.9	4.23fgh	7.16ef	8.740h	13.87fg	12.63cd
$V_4 \times T_5$	42.43	64.43g-k	81.3 f	94.53	104.5	3.86g-j	6.43fg	8.033i	13.50g	12.40d
Sx	1.03	1.53	1.71	2.01	2.37	0.233	0.234	0.189	0.328	0.325
Significance Level	NS	**	*	NS	NS	**	**	**	**	**
CV (%)	4.05	3.83	3.35	3.50	3.74	8.58	5.33	3.07	3.86	4.12

Values in the same column that share identical letters are statistically equivalent.

**= Significant at 1% level of probability, *= Significant at 5% level of probability, NS = Not significant.

V_1 = Kalizira, V_2 = Binadhan-13, V_3 = BRRI dhan34, V_4 = BRRI dhan38

T_1 = Control (no manure and fertilizer), T_2 = RDU 150 kg /ha, T_3 = 50% RDU, T_4 = 50% RDU + PM 5 t/ha, T_5 = 50% RDU + PM 2.5 t/ha.

Table 2. Interaction effect of variety with nutrient management on LAI and TDM of aromatic fine rice.

Interaction	Leaf Area Index (LAI)					Total Dry Matter (TDM)				
	DAT					DAT				
	30	45	60	75	90	30	45	60	75	90
$V_1 \times T_1$	1.08h	2.13e-i	2.81g-i	4.63gh	3.76e-h	2.46gh	6.00h	11.33f	23.67e	30.4ef
$V_1 \times T_2$	1.97bc	2.59b-d	2.94f-h	5.67ab	3.81e-h	2.87ef	7.86b-d	12.43d	24.60e	31.30d-f
$V_1 \times T_3$	1.81cd	2.45c-e	2.92f-i	5.07de	3.80e-h	2.73fg	6.82fg	11.77d-f	24.87e	30.70d-f
$V_1 \times T_4$	1.99bc	2.65b-d	3.88ab	5.80ab	4.15cd	3.53c	8.68a	16.87ab	25.13e	32.70d
$V_1 \times T_5$	1.86cd	2.26d-g	3.46c-e	5.24cd	4.20c	3.033de	7.80b-d	12.47d	24.53e	31.67de
$V_2 \times T_1$	1.11gh	2.34e-i	3.16e-g	4.20j	3.48hi	2.33hi	6.64g	11.42f	23.63e	25.77j
$V_2 \times T_2$	1.76c-e	2.67bc	3.59b-d	4.57ghi	3.93c-f	2.90ef	7.42de	13.20c	27.37d	29.30f-h
$V_2 \times T_3$	1.54d-f	2.16ef-i	3.42c-e	4.39hij	3.53ghi	2.46gh	6.66g	12.20de	25.10e	26.40ij
$V_2 \times T_4$	2.00bc	2.89ab	4.05a	5.48bc	4.567 b	3.36cd	7.63cd	13.77c	27.8d	29.53e-g
$V_2 \times T_5$	1.80cd	2.45c-e	3.42c-e	4.70fgh	3.73e-h	2.80efg	7.29d-f	13.57c	27.47d	29.37f-h
$V_3 \times T_1$	1.90c	2.18e-h	3.26d-f	4.98def	4.03cde	2.59fgh	7.43de	13.32c	24.30e	30.87d-f
$V_3 \times T_2$	2.04bc	2.67bc	3.70a-c	5.73ab	4.873b	3.88b	8.30ab	13.6c	38.87b	48.20b
$V_3 \times T_3$	2.60a	2.41c-f	3.51b-e	5.10de	4.59b	3.03de	7.83b-d	13.9c	29.37c	37.47c
$V_3 \times T_4$	2.68a	3.21a	4.05a	5.85 a	5.20a	4.297a	8.73a	17.44a	41.47a	51.27a
$V_3 \times T_5$	2.29b	3.11a	3.74a-c	5.80ab	4.56b	3.33cd	8.10bc	16.40b	37.97b	48.07b
$V_4 \times T_1$	0.99h	1.67j	2.46i	4.14j	3.33i	1.930j	6.30gh	11.17f	21.58f	27.17h-j
$V_4 \times T_2$	1.47ef	1.84h-j	2.75hi	4.46h-j	3.70e-h	2.30hi	6.80fg	11.80d-f	24.30e	27.67g-j
$V_4 \times T_3$	1.47ef	1.76j	2.54i	4.26ij	3.46hi	2.01ij	6.62g	11.40f	24.20e	27.50g-j
$V_4 \times T_4$	1.93c	2.03f-j	2.80g-i	4.81e-g	3.86d-g	2.58f-h	6.86e-g	12.47d	24.63e	28.03g-i
$V_4 \times T_5$	1.42fg	1.99h-j	2.767i	4.68f-h	3.66f-h	2.23h-j	6.82fg	11.63ef	24.40e	27.83g-j
Sx	0.104	0.123	0.118	0.105	0.103	0.116	0.189	0.230	0.498	0.685
Significance Level	*	*	*	**	**	**	**	**	**	**
CV (%)	10.17	9.11	6.24	3.61	4.43	7.06	4.49	3.04	3.17	3.65

Values in the same column that share identical letters are statistically equivalent.

**= Significant at 1% level of probability, *= Significant at 5% level of probability, NS = Not significant.

V_1 = Kalizira, V_2 = Binadhan-13, V_3 = BRRI dhan34, V_4 = BRRI dhan38, T_1 = Control (no manure and fertilizer), T_2 = RDU 150 kg /ha, T_3 = 50% RDU, T_4 = 50% RDU + PM 5 t/ha, T_5 = 50% RDU + PM 2.5 t/ha.

Table 3. Interaction effect of variety with nutrient management on CGR of aromatic fine rice

Interaction (Variety × Nutrient management)	CGR (g/m^2 per day) x 10^3			
	DAT			
	30-45	45-60	60-75	75-90
$V_1 \times T_1$	0.640h	0.95cdef	2.22g	1.21cd
$V_1 \times T_2$	0.90ab	0.82f	2.19g	1.20cd
$V_1 \times T_3$	0.74g	0.89def	2.36efg	1.05d
$V_1 \times T_4$	0.93a	1.477a	1.48i	1.36c
$V_1 \times T_5$	0.86bcd	0.84ef	2.17g	1.28bc
$V_2 \times T_1$	0.77efg	0.85ef	2.20g	0.38f
$V_2 \times T_2$	0.81def	1.04bcd	2.55e	0.35f
$V_2 \times T_3$	0.75fg	0.99bcde	2.32fg	0.23f
$V_2 \times T_4$	0.77efg	1.10bc	2.53e	0.30f
$V_2 \times T_5$	0.80def	1.13b	2.50ef	0.34f
$V_3 \times T_1$	0.87bc	1.05bc	1.97h	1.18cd
$V_3 \times T_2$	0.79efg	0.96def	4.533a	1.69a
$V_3 \times T_3$	0.86bcd	1.09bc	2.77d	1.45b
$V_3 \times T_4$	0.79efg	1.56a	4.32b	1.76a
$V_3 \times T_5$	0.85bcd	1.49a	3.88c	1.81a
$V_4 \times T_1$	0.79efg	0.87ef	1.87h	1.01d
$V_4 \times T_2$	0.81def	0.89def	2.25g	0.60e
$V_4 \times T_3$	0.83cde	0.86ef	2.30fg	0.59e
$V_4 \times T_4$	0.77efg	0.99bcde	2.20g	0.61e
$V_4 \times T_5$	0.8267de	0.86ef	2.29fg	0.61e
Sx	0.018	0.048	0.065	0.068
Significance Level	**	**	**	**
CV (%)	4.43	7.91	4.45	11.81

Values in the same column that share identical letters are statistically equivalent.
**= Significant at 1% level of probability, *= Significant at 5% level of probability, NS = Not significant.
V_1 = Kalizira, V_2 = Binadhan-13, V_3 = BRRI dhan34, V_4 = BRRI dhan38
T_1 = Control (no manure and fertilizer), T_2 = RDU 150 kg /ha, T_3 = 50% RDU, T_4 = 50% RDU + PM 5 t/ha, T_5 = 50% RDU + PM 2.5 t/ha.

No significant variation was noticed between interactions in thousand-grain weight of aromatic fine rice. The grain yield, straw yield and harvest index were considerably influenced by each treatment and their interactions. The data clearly showed that BRRI dhan34 produced the highest grain yield (3.67 t/ha) followed by Binadhan-13 and lowest grain yield was recorded in BRRI dhan38 (Figure 2a). Treatment T_4 (50% RDU + PM 5 t/ha) generated the maximum grain production (3.57 t/ha). The control treatment produced the lowest grain yield (3.19 t/ha) (Figure 2b). The highest grain yield (3.79 t/ha) was attained from BRRI dhan34 with 50% RDU + PM at 5 t/ha ($V_3 \times T_4$) treatment followed by $V_3 \times T_3$ and the lowest grain yield (3.05 t/ha) was achieved from the combination $V_4 \times T_1$ (BRRI dhan38 with control treatment) (Figure 2c). The highest straw yield (5.126 t/ha) was produced in T_4 treatment and the lowest straw yield (3.99 t/ha) was produced in controlled treatment.

Table 4 Shows that the maximum straw yield (5.70 t/ha) was gained from the interaction $V_3 \times T_4$ (BRRI dhan34 with 50% RDU + PM 5 t/ha) which was at par with $V_1 \times T_4$, $V_1 \times T_3$ and $V_1 \times T_5$ whereas the lowest one (3.23 t/ha) was attained from the interaction $V_1 \times T_1$. HI showed a considerable fluctuation as a result of the interaction effect. The highest harvest index (49.92%) was noticed in treatment interaction $V_1 \times T_1$ which was at par with $V_4 \times T_1$ and the lowest one (39.33%) was documented in $V_1 \times T_5$. In terms of economic performance, the treatment combination $V_3 \times T_4$ (BRRI dhan34 with 50% RDU with PM 5 t/ha) yielded the highest returns, achieving the maximum benefit-cost ratio of 1.71. In contrast, the $V_4 \times T_1$(BRRI dhan38 with control treatment) treatment resulted in the lowest economic gain, recording a benefit-cost ratio of just 1.25.

Table 4. Yield contributing characters and yield of aromatic fine rice as influenced by interaction (Variety × Nutrient management).

Variety × Nutrient management	Effective tillers/hill (no.)	Non-effective tillers /hill (no.)	Panicle length (cm)	Grains /panicle (no.)	Sterile spikelets /panicle (no.)	1000 - grain weight (g)	GY (t/ha)	SY (t/ha)	HI (%)	Benefit -cost Ratio
$V_1×T_1$	5.73i	1.60e-h	21.00hi	135.3ab	10.73fg	12.07	3.22ij	3.23k	49.92a	1.41
$V_1×T_2$	9.50fg	2.50cd	23.00gh	132.3ab	23.67a-d	12.67	3.40d-g	4.96b-f	40.65fg	1.47
$V_1×T_3$	8.6gh	1.95de	21.6h-j	131.3ab	22.00cde	12.10	3.47c-f	5.11a-d	40.41fg	1.50
$V_1×T_4$	12.00ab	1.00h-j	22.67g-i	135.7ab	24.3abc	14.10	3.51cd	5.23ab	40.15g	1.61
$V_1×T_5$	10.8c-e	1.17 f-j	22.00h-j	135.3ab	24.00bc	13.77	3.37d-h	5.20abc	39.33g	1.46
$V_2×T_1$	7.66h	2.330d	21.83h-j	126.3b	8.333gh	11.77	3.17jk	4.43 e-h	41.74efg	1.29
$V_2×T_2$	10.00ef	2.33d	24.00ef	134.3ab	12.00 f	12.33	3.35e-i	4.56c-g	42.81d-g	1.55
$V_2×T_3$	10.33ef	1.67e-g	23.0f-h	135.0ab	11.33fg	12.20	3.25h-j	4.50d-g	42.24efg	1.42
$V_2×T_4$	11.64a-d	1.700ef	24.33de	135.0ab	23.00b-d	13.17	3.60bc	5.20abc	40.91fg	1.64
$V_2×T_5$	10.33ef	3.00bc	23.33e-g	134.3ab	19.33e	12.80	3.23h-j	4.63b-f	41.08fg	1.41
$V_3×T_1$	8.00h	4.00a	22.67g-i	133.3ab	20.67de	12.50	3.33f-i	4.97b-f	40.14g	1.45
$V_3×T_2$	11.67a-d	1.00h-j	25.6bc	138.0a	25.33abc	12.83	3.51cd	5.20a-c	40.30fg	1.51
$V_3×T_3$	10.67de	1.67e-g	25.3cd	136.3a	25.33abc	13.33	3.66b	5.26ab	40.98fg	1.56
$V_3×T_4$	12.67a	1.00h-j	27.40a	139.3a	27.00a	14.33	3.79a	5.70a	39.96g	1.71
$V_3×T_5$	11.77a-c	0.57j	26.67ab	138.7a	26.33ab	14.13	3.49c-e	5.03b-e	40.95fg	1.50
$V_4×T_1$	5.33i	1.40e-h	20.67j	114.7c	7.63h	11.10	3.05k	3.33jk	47.78ab	1.25
$V_4×T_2$	7.66h	3.33b	21.67h-j	134.0ab	12.00f	11.95	3.30g-j	3.87h-j	46.05b-d	1.34
$V_4×T_3$	8.66gh	1.333f-i	21.33ij	132.7ab	11.00fg	11.41	3.17jk	3.63i-k	46.66bc	1.69
$V_4×T_4$	11.00b-e	1.06g-j	22.67g-i	135.0ab	12.33f	12.13	3.41d-g	4.37f-h	43.85c-f	1.47
$V_4×T_5$	9.91ef	0.75ij	21.22j	132.3ab	12.00f	11.33	3.24h-j	4.00g-i	44.77b-e	1.42
Sx	0.331	0.187	0.407	2.75	1.02	0.591	0.045	0.195	1.05	
Significance Level	**	**	**	*	**	NS	*	**	**	
CV (%)	5.91	18.32	3.05	3.58	9.88	8.16	2.27	7.29	4.30	

Values in the same column that share identical letters are statistically equivalent.
**= Significant at 1% level of probability, *= Significant at 5% level of probability, NS = Not significant.
V_1 = Kalizira, V_2 = Binadhan-13, V_3 = BRRI dhan34, V_4 = BRRI dhan38
T_1 = Control (no manure and fertilizer), T_2 = RDU 150 kg /ha, T_3 = 50% RDU, T_4 = 50% RDU + PM 5 t/ha, T_5 = 50% RDU + PM 2.5 t/ha.

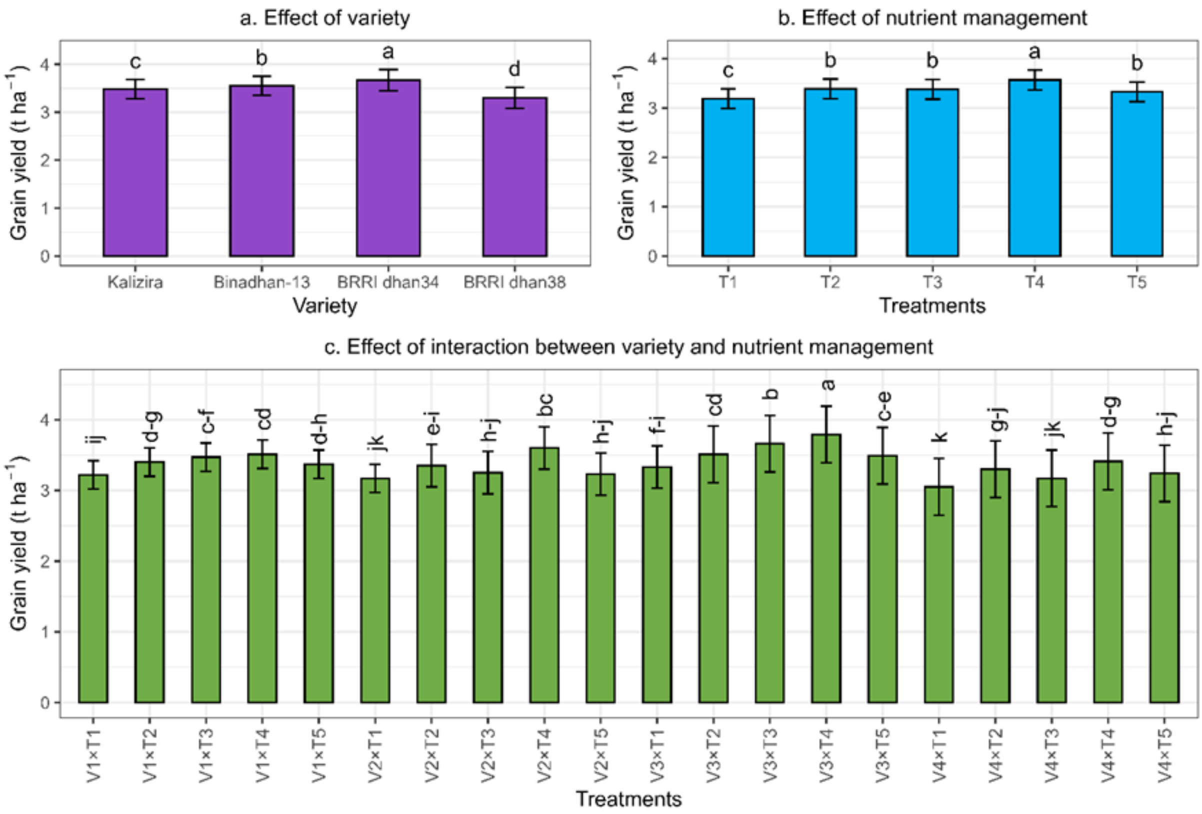

Fig. 2. Effect of variety (a), integrated nutrient management (b) and their interactions (c) on the yield of aromatic fine rice.

Functional relationship

The Leaf Area Index (LAI) is crucial for aromatic rice production, indicating the photosynthetic area available to plants. A strong correlation exists between grain yield and LAI (R^2 = 0.6785**) (Figure 3a), implying that higher LAI boosts grain production, as noted by Ray et al. (2015) and Paul et al. (2016). Total Dry Matter (TDM) also significantly influences yield, reflecting how dry materials are allocated to grains. There is a positive correlation between grain yield and TDM (R^2 = 0.5679**) (Figure 3b), suggesting that increased TDM leads to higher grain yields, consistent with Ray et al. (2015).

Discussion

In the present study, BRRI dhan34 exhibited superior morphological and physiological traits and yield characteristics, resulting in the highest yield among the evaluated varieties (Kalizira, Binadhan-13, and BRRI dhan38). BRRI dhan34 may possess superior genetic traits for vigorous growth, efficient resource utilization, and higher photosynthetic efficiency. The higher productive tiller production, grain filling, and better spikelet fertility likely contribute to its superior yield performance. These findings align with previous reports by Abo-Yousef et al. (2024), Halawa and Mohamed (2024), Tyeb et al. (2013) and Islam et al. (2013) who documented that varietal differences in growth and yield are primarily attributed to genetic variation.

Growth attributes such as plant height, tiller number per hill, and total dry matter (TDM) accumulation were significantly enhanced by the integrated use of poultry manure (PM) and inorganic fertilizer, particularly the 50% RDU + PM (5 t/ha) treatment. The low carbon-to-nitrogen (C/N) ratio of poultry manure (approximately 12:1) promotes rapid mineralization, providing both immediate and sustained nutrient availability. This dual nutrient-release mechanism supports optimal plant development across growth stages (Ge et al., 2010; Hidayatullah et al., 2013). PM acts as a dual-action fertilizer, offering both quick-acting and slow-release nitrogen, which makes it an excellent choice for sustainable agriculture. It has been observed that during growth stage most of the characters *viz.* plant height, tillers/hill and TDM gave highest values at 50 % RDU + PM (5 t/ha) while their least values were found in control (no manure and fertilizer). In addition, the gradual nitrogen release from PM reduces losses through volatilization and leaching, common in urea-based systems (Amanullah et al., 2016), thus enhancing nitrogen-use efficiency.

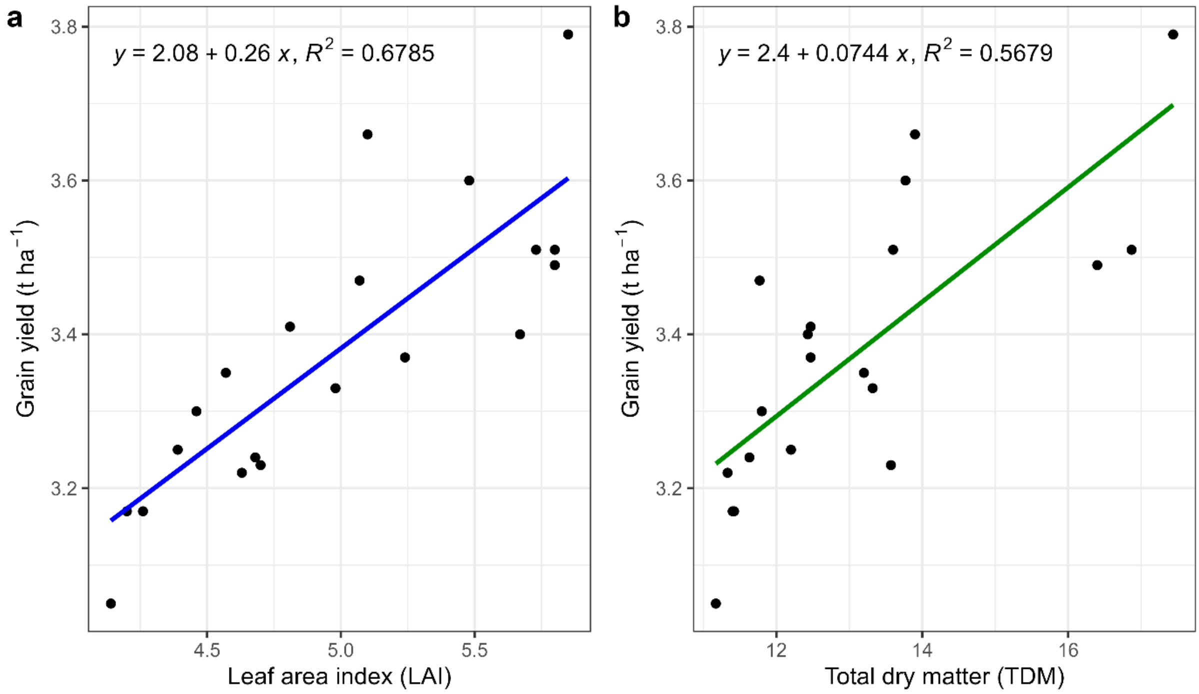

Fig. 3. Relationship between growth attributes (LAI and TDM) and grain yield of aromatic fine rice.

The highest grain and straw yields were recorded under integrated use of poultry manure (PM) and inorganic fertilizer, particularly the 50% RDU + PM (5 t/ha) treatment, which offered a balanced nutrient supply that improved vegetative vigor, tiller production, and assimilate accumulation. This treatment also promoted improved grain filling and panicle productivity, demonstrating the effectiveness of integrated nutrient management in fine aromatic rice systems. The highest benefit-cost ratio (1.71) was achieved under this treatment, demonstrating superior economic viability. In contrast, the lowest BCR (1.25) was associated with low-input and less productive combinations, indicating limited profitability. Notably, although the control plots received no fertilizers, they still produced a considerable yield. This can be attributed to the inherent baseline soil fertility, favorable agro-climatic conditions, and the nutrient-use efficiency of BRRI dhan34, which collectively supported modest growth and productivity in the absence of external inputs.

Previous studies support the advantages of combining organic and inorganic fertilizers to enhance yield and crop quality (Sarkar et al., 2014; Islam et al. 2015; Biswas et al., 2016; Pal et al., 2016; Jahan et al., 2017; Paul et al., 2023). Qian et al. (2011) and Paul et al. (2025) reported similar findings, indicating that the integrated use of inorganic and organic fertilizers boosts rice grain production. The integrated appliance of organic and inorganic nitrogen fertilizers can significantly enhance the panicles/ sqm, panicle weight, panicle length, filled grains/panicle, 1000-grain weight, and overall rice grain yield (Khan et al., 2004; Salem, 2006; Antil and Singh, 2007). Many Asian rice-growing regions have recently shown significant interest in using organic sources in conjunction with mineral nitrogen fertilizer (Myint et al., 2010). Variety and nutrient management interacted to greatly affect yield and yield contributing characteristics. Sarkar et al. (2014) also observed that BRRI dhan34 produced the highest yield when integrated with 75% RDU and 50% cow dung, further validating our results.

Finally, the increase in harvest index observed in the control may be attributed to lower straw biomass resulting from reduced tillering, even though grain yield remained relatively stable. The consistent supply of nutrients in integrated treatments, particularly the synergy of slow-release PM and fast-acting urea, enhanced growth parameters, photosynthetic efficiency, and grain development. Therefore, integrated nutrient management stands out as a sustainable and effective strategy to enhance yield potential and physiological performance in aromatic rice cultivation under subtropical conditions.

Conclusion

This experiment demonstrated that the collective use of organic and inorganic nutrient management notably enhances growth and yield of aromatic fine rice. Among treatments, the combination of 50% recommended dose of urea (RDU) with poultry manure (PM) at 5 t/ha showed superior performance in improving morphological and physiological traits, yield components and overall productivity of aromatic fine rice. Among tested rice varieties, BRRI dhan34 produced maximum grain yield under this nutrient management regime. These findings underscore the importance of combining appropriate nutrient management practices with suitable rice varieties to achieve sustainable productivity. Importantly, this integrated approach also proved to be economically beneficial, as it achieved the highest benefit-cost ratio (BCR) among all treatments, indicating enhanced profitability alongside productivity. In conclusion, the application of 50% RDU with PM (5 t/ha) is recommended as an effective nutrient management for enhancing yield of fine rice, particularly for the variety BRRI dhan34. Future research should explore further aspects of this approach on nutrient management and its economic viability for broader adoption in fine rice cultivation.

Author contribution:

The manuscript was edited and revised by all authors.

Conflicts of Interest:

The author declares no conflict of interest.

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