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Effect of Integrated Nitrogen Management on Growth and Yield Characteristics of Local and Modern Aromatic Rice cultivars in Bangladesh

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A THE CURRENT study was conducted to evaluate the effect of integrated nitrogen management on growth and yield performance of six aromatic rice varieties. The experiment involved six aromatic rice varieties: V_1 (BR5), V_2 (BRRI dhan34), V_3 (BRRI dhan37), V_4 (BRRI dhan70), V_5 (Kalijira), and V_6 (Chinigura), with five nitrogen treatments being applied. Results showed that the T_5 treatment produced the tallest plants (156.8 cm), the highest tiller count (483.3 m^{-2}), and highest leaf area index (6.79). The maximum TDM (75.14 g $hill^{-1}$) and RGR (0.17 g/g/day) were observed with T_4 treatment in BR5 and BRRI dhan70. The highest CGR (28.12 g/m²/day) was achieved with T_5 treatment in BR5. BRRI dhan70 had the uppermost grain yield (4.53 t ha^{-1}) under T_4 treatment, while Kalijira had the least yield (1.68 t ha^{-1}) in the control. Multivariate analysis confirmed the superiority of T_4 in BRRI dhan70 and distinguished modern from local varieties based on growth and yield traits. The findings suggest that BRRI dhan70, combined with T_4 treatment, is optimal for maximizing yield among the varieties tested.

Keywords: Aromatic rice; integrated nitrogen management; growth and yield.

Introduction

Bangladesh is a rice dominating country in the world where rice (*Oryza sativa* L.) is grown mainly in a monoculture system over the vast area of agricultural land. About 90% of the rice produced in the world comes from tropical and subtropical regions of Asia, which makes this a very important crop (**Mejia, 2006**). Most of the cropped land in Bangladesh, rice occupies around almost 77.07% providing a total annual yield of about 36.60 million tons from an area of 11.42 million hectare with average productivity estimated as low as 3.06 tons ha^{-1}, which remains relatively less than the overall world average ranging approximately between (6–6.5-ton ha^{-1}) (**BBS,2020**). Nonetheless the nation has this far larger than usual yield gap, yet at the same time it is positioned as third biggest rice maker on the planet after China and India (**BARC 2021**). Against this background, T. *Aman* rice is second largest crop in Bangladesh production volume (**BBS, 2015**). During the rainy T. *Aman* season, various aromatic rice varieties are cultivated. Although most aromatic rice varieties have lower yield potential, their strong consumer demand and high market price make breeding for aroma a difficult task (**Kader et al., 2018**). Leaving aside the above economic studies, aromatic rice of Bangladesh has entered global market (with proper provision and research) in recent years based on its own highly appealing taste and aroma with appeal to businessmen providing an input towards a better social condition for rice growers in Bangladesh.

Breeding aromatic rice is challenging due to their photoperiod-sensitive nature, with slight changes in day length significantly affecting local cultivars in Bangladesh. Additionally, traditional tall aromatic rice varieties suffer from lodging, which causes yield loss. This is due to their long, drooping leaves and weak stems, which encourage lodging and limit yield potential (**Chakma, 2021**). Modern varieties, by contrast, have generally short and stiff culms which support more bending but are more study against lodging; they also have dark green leaves with higher levels of anti-lodging properties. Over the past three decades, the widespread adoption of high-yielding rice varieties and heavy fertilizer use in Bangladesh has led to a decline in soil fertility. This has resulted in nutrient depletion and reduced organic matter. To address this, integrated nitrogen management strategies have been incorporated into agricultural policies, aiming to optimize fertilizer use and sustain productivity.

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However, challenges like weak soil governance and land overexploitation remain, highlighting the need for sustainable soil management practices (**Khan and Shoumik, 2022**), which are declining or stagnant. N is the single most significant nutrient restraining rice and other crop production in highly productive areas globally. Therefore, implementing effective nitrogen management practices could provide significant economic advantages to farmers. The past few decades have elevated the concept of organic manures for enriching soil health, contributing to soil properties and supplying whole range of nutrients needed for plants growth. Organic manures are important sources of nutrients for maintaining the sustainable productivity of rice-based cropping system under organic farming systems (**Dahiphale *et al.*, 2003**).

Organic farming practices are also on the rise due to consumer demand for organic, high-quality and ethically produced food. Despite this, there is a rising demand for quality organic products on the international platform which indicates that Bangladesh should harbinger organic farming on a larger scale.

Sustainable soil health improvement can be achieved by combining organic and inorganic elements of nutrient management, which has the potential to enhance rice productivity. Although there are some negative consequences associated with them, chemical fertilizers have proved useful in helping attain yield advances and could help cover about 50% of overall advancement in food grain production, which is essential for fulfilling the food requirements of this ever-increasing population in Bangladesh. Integrated nutrient management (INM) is aimed at improving soil health for sustainable productivity (**Prasad *et al.*, 1995**). The application of both organic and inorganic fertilizers enhances rice productivity and nutrient use efficiency (**Singh and Kumar, 2014**). Explaining optimum times of plant nutrient absorption, organic provision of nutrients guarantees micronutrient availability in the fertilizer while at peak requirement periods, with benefits to soil physical characteristics and rise in usage by plants (**Pandey *et al.*, 2007**). An integrated use of nitrogen sources not only meets the requirements for rice crops but also assigns sustainable productivity targets on a larger scale (**Singh and Kumar, 2014**).

Therefore, it has been researched on INM based on the above considerations for realizing the effective sources of nitrogen and their optimum application rates to obtain physiological growth response from rice which ultimately adjoins to its yield. The rationale behind this is to enhance rice yield with minimal detrimental impact on the environment and the livelihood of rice farmers in Bangladesh. This study aimed to evaluate the effects of integrated nitrogen management on growth, yield, and yield components of six aromatic rice varieties in Bangladesh.

Materials and Methods

Site of the experiment The study was designed as a field trial at the Bangladesh Rice Research Institute (BRRI) in Gazipur, Bangladesh, during the T. Aman season of 2018. The location is situated at 23°59'33" N and 90°24'19" E, with an elevation of 8.4 m above sea level, characterized by a subtropical climate. Madhupur tract (AEZ 28) was the place under Agro-ecological Zone. The soil characteristics of the experimental site were clay loam having (pH 6.73) slightly acidic, organic matter (1.58%), total N (0.11%), available phosphorus (5.03ppm), Exchangeable potassium (K) (meq/100g soil) (0.23) in 0-15 cm soil depth at the beginning of the experiment. The highest and lowest temperatures during the period of study were 14.790C, 34.410C and mean monthly relative humidity was recorded to be 78.20% respectively. The first three months are when heavy rainfall occurs (**Table 1a, 1b**).

Table 1a. Average Temperature, Rainfall, Relative humidity, Sunshine and Cloudy during the experimental period (July 2018 to December 2018) at BRRI farm, Gazipur.

Months	Avg. Max. Temp. (^{0}C)	Avg. Min. Temp. (^{0}C)	Avg. Mean Temp. (^{0}C)	Avg. Rainfall (mm)	Avg. R.H. (%)	Avg. Sunshine hrs/day	Avg. Cloudy hrs/day
July	32.58	26.37	29.47	11.65	83.69	4.41	9.09
August	34.41	26.77	30.59	5.25	78.11	6.07	6.83
September	34.31	26.31	30.31	4.51	75.56	6.11	6.11
October	32.10	23.17	27.63	2.17	72.43	5.89	5.61
November	30.84	18.59	24.71	1.35	65.24	7.35	3.51
December	27.08	14.79	20.93	0.31	66.93	6.10	4.31

Source: BRRI Agro meteorological Station, Plant physiology Division, Gazipur, Bangladesh.

Table 1b. Average Evapotranspiration, Solar radiation and Growing degree days during the experimental period (July 2018 to December 2018) at BRRI farm, Gazipur).

Months	Avg. Evapotranspiration mm/day	Avg. Solar radiation Cal/cm^2/day	Avg. Growing degree days (GDD)
July	100.29	329.68	19.47419
August	80.47	386.42	20.59194
September	117.12	346.70	20.31129
October	86.01	314.60	17.63387
November	58.97	309.58	14.71694
December	47.12	264.06	10.93871

Source: BRRI Agro meteorological Station, Plant physiology Division, Gazipur, Bangladesh.

Experimental details

The study was designed by using a Randomized Complete Block Design (RCBD) design with 3 replications. The plot size of the unit was 5.0 m × 4.0 m and plant spacing was maintained at 20 × 20 cm. It was a two-factor experiment: INM (Integrated Nutrient Management) and Variety. The factorial combinations included five organic and inorganic nitrogen management viz., T1: Control (No N), T2: BRRI RD of N from urea, T3: 70 % of the RD of N from urea + 30 % N from cow dung, T4: 70 % of the RD of N from urea + 30 % N from vermicompost, and T5: 70 % of the RD of N from urea + 30% N from poultry manure and six aromatic rice varieties viz. V1: BR5, V2: Kalijira, V3: Chinigura, V4: BRRI dhan34, V5: BRRI dhan37, V6: BRRI dhan70. The land was fertilized according to the specification of treatment. For the final land preparation, each unit plot was treated with the recommended levels of cow dung, vermicompost, bio-slurry, and poultry manure. These organic materials were thoroughly mixed with the soil to ensure uniform distribution. However, the ethical considerations related to the environmental safety of manure use were not addressed in the methods section. Including a brief discussion on the sustainable and safe application of organic manures would enhance the methodology by demonstrating a commitment to minimizing potential environmental impacts, such as soil degradation and water contamination, thus ensuring responsible agricultural practices. For total land, the required amounts of nitrogen, phosphorus, potassium, sulfur, and zinc were calculated on a per-hectare basis and applied as urea, triple super phosphate, muriate of potash, gypsum, and zinc sulfate, respectively. The nitrogen balance was determined based on the IPN system, and the minimum required quantities were applied through fertilizers. The necessary doses of TSP, MoP, gypsum, and zinc sulfate were applied to the unit plots during the final stage of land preparation. Urea requirement was given in three equal splits by top dressing on 15, 30 and 45 DAT. Treatment for the nitrogen provided to the crop its sources and rates are presented below. The seedlings were pulled up with great care without hurting the roots and planted back into the main field. All intercultural operations were carried out as required.

Harvesting and data collection

Rice was harvested with 80–90% of grain at physiological maturity. A total of ten hills, excluding the border hills, were randomly selected from each unit plot, except a one-square meter section used for yield estimation. Morphological traits of association studies were yield-related traits and growth character like plant height at different DAT, number of total tillers m-2 at different DAT, LAI, TDM, CGR and RGR at different growth stages (DGS) (active and maximum tillering stage, booting and flowering stage) were estimated.

Plant height (PH)

PH was measured in centimeters from the bottom to the top of the flag leaf using five randomly selected sample hills plot^{-1}. The measurements were taken individually, and the average height was calculated and recorded.

Number of total tillers (NTT m^{-2})

NTT was noted from the selected hills at 15, 30, 45, 60, 75, 90, and 105 days after transplanting (DAT). Tillers bearing at least one visible leaf were considered in the count.

Leaf area index (LAI)

The LAI was measured utilizing a leaf area meter (Model: LI-3000) and subsequently calculated using the following formula:

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

Where,

LA = the total leaf area (cm^2)

P = the ground area occupied by the plant (cm^2)

Total dry matter (TDM)

TDM production was determined by aggregating the dry weights of all plant components from an individual hill, including the leaf, stem, panicle, and root. This total was then normalized on a per-unit basis for further analysis of TDM constituents and related evaluations. Dry weights of the leaf, sheath, panicle, and root were subsequently measured at key growth stages: the Active Tillering Stage (ATS), Maximum Tillering Stage (MTS), Booting Stage (BS), Flowering Stage (FS), and Maturity

Stage (MS). Samples were oven-dried at 70°C for 72 hours to obtain the respective dry weights.

Crop growth rate (CGR)

The plant samples were collected and subsequently oven-dried at 70°C for 72 hours to calculate the CGR (Radford, 1967). Shoot dry weight was recorded from 15 DAT up to crop maturity, with measurements taken at 15-day intervals. The CGR was calculated using the following equation:

CGR (g/m^{-2}/day) = $\frac{W_2 - W_1}{T_2 - T_1}$

Where,

T_1 = day of starting

T_2 = day of final record

W_1 = dry weight at T_1

W_2 = dry weight at T_2

Relative growth rate (RGR)

The rate at which dry matter accumulates in the plant is measured as the total dry weight over a given period or as the mean of the RGR between two points (Tanaka et al., 1996). The RGR was calculated using the formula provided below:

RGR (g/g/day) = $\frac{(\ln W2 - \ln W1)}{T2 - T1}$

Where, ln = Natural logarithm

T_1= time one (in day)

T_2 = time two (in day)

W_1 = dry weight of plant in grams at one time

W_2 = dry weight of plant in grams at two times

Grain yield

At crop maturity, plants were harvested by cutting all specimens from a 5 m² sample area at the base. After threshing and cleaning, the fresh weight of the grains was recorded and then adjusted to a moisture content of 14% using the formula outlined:

Grain yield = $\frac{FW(100 - MC)}{100 - 14}$

Where,

FW = fresh weight of the grains

MC = % moisture content in fresh grains

Straw yield

The straw collected from the harvested plot samples was dried and weighed. To determine the moisture content, the samples were subjected to oven-drying at 70°C for a duration of 72 hours. The SY was then adjusted to a 14% moisture content and converted to t ha^{-1}.

Harvest index

The HI, defined as the ratio of economic yield to biological yield, was calculated using the formula provided below (**Gardner *et al.*, 1985**):

Harvest index (%) =$\frac{\text{Economic yield}}{\text{Biological yield}}$ x 100

Where,

Economic yield = grain yield

Biological yield = grain yield + straw yield

Statistical analysis

The data collected from the various experiments were subjected to statistical analysis. Analysis of variance (ANOVA) for the different parameters was performed using R version 3.4.1 software. Following the ANOVA, differences among treatment means were assessed using Duncan's New Multiple Range Test (DMRT) at the 1% and 5% levels of significance (**Gomez and Gomez, 1984**).

Results:

Effect of nitrogen

The effects of nitrogen management on PH (Plant Height), NTT (Number of Total Tillers) hill^{-1} (m²), LAI (Leaf Area Index), TDM (Total Dry Matter), CGR (Crop Growth Rate), and RGR (Relative Growth Rate) were highly significant (**Fig. 1–6**). The results indicate that the maximum PH of 136 cm was recorded at 90 DAT, observed in the T_4 treatment, followed by the T_5 treatment. Similarly, the highest total tiller count of 415 was recorded at 45 DAT with T_4 treatment. All treatments were statistically comparable to each other and significantly superior to the control. With respect to LAI value, the highest value, 32.96, was recorded at buyo stage and it was due to the T_4 treatment. The lowest LAI value of 0.67 was recorded during the active tillering stage. Similarly with respect to TDM production, the highest 54.64 g hill^{-1} value was recorded at maturity stage due to the T_4 treatment, whereas the lowest 3.33 g was noticed at active tillering stage in control. The highest CGR value was recorded at BS (Booting stage) and was found to be 18.72 g m^{-2} day^{-1} in the above-mentioned treatment. The lowest of 1.3 was recorded at ATS (Active tillering stage). With reference to RGR, the highest of 0.1 was recorded at maturity stage for the same and the lowest value of 0.01 g g^{-1} day^{-1} was recorded for ATS (**Fig. 1-6**

Impact of variet

The result of variety was significantly affected by PH, NTT m^{-2}, LAI, TDM, CGR, and RGR (**Fig. 1-6**). Kalijira was the maximum PH at all sampling data, reaching the highest PH of 157.2 cm at 90 DAT, while the shortest plant, measuring 120.4 cm, was found in BRRI dhan34 at the same DAT (**Fig. 1**). Tiller production increased overtime, peaking between 15 and 45 DAT before decreasing after 60 DAT. The uppermost NTT (425 m^{-2}) was recorded in Chinigura, followed by Kalijira at 45 DAT, which then declined to 60 DAT, with the lowest count (347.8) observed in BRRI dhan70 at this same DAT (**Fig. 2**).

The results showed that BRRI dhan70 provided the highest LAI (6.56) at the BS, while the lowest LAI (0.66) was observed in BR5 at the ATS (**Fig. 3**). The maximum TDM (66.19 g hill^{-1}) was noted in BR5 at the MS, while the lowest TDM (42.96 g hill^{-1}) was observed in BRRI dhan37 at the same stage (**Fig. 4**). The utmost CGR (24.53 g m^{-2}day^{-1}) was recorded from the BS to FS in BRRI dhan70, while the least CGR (0.68 g m-2day-1) was observed in Kalijira from the ATS to MTS (**Fig. 5**). The highest

RGR (0.15 g $g^{-1}day^{-1}$) was obtained between the MTS to BS in BRRI dhan70, while the lowest RGR (0.01 g $g^{-1}day^{-1}$) was recorded in Chinigura, followed by BRRI dhan34, BRRI dhan37, and Kalijira from FS to MS (**Fig. 6**). The superior performance of BRRI dhan70 under T4 may be attributed to efficient utilization of both chemical and organic nitrogen sources, while Kalijira's tall stature may relate to its varietal genetic potential for elongation.

Interaction effect of INM and variety

At 105 DAT, the tallest plant (156.8 cm) was found in the Kalijira variety under the application of T5 treatment. In contrast, the lowermost PH (36.9 cm) at 15 DAT was recorded in the control treatment with BRRI dhan70 (**Fig. 7**). The highest NTT (483.3m^{-2}) at 45 DAT was recorded in Chinigura, under the integrated nitrogen treatments (T_3, T_4 and T_5), along with BRRI dhan37 under the same nitrogen regime and growth stage. The minimal NTT (125 m^{-2}) was found in control with BR5 at 15 DAT (**Fig. 8**).

The LAI was generally unaffected by the interaction between INM and variety, except during the ATS. The highest LAI (6.79) at the BS was recorded in BRRI dhan70 under the T5 treatment. This was statistically like the LAI observed with the BRRI RD N and the combination of T4 treatment for the same variety at the same stage. The least LAI (0.63) was noted in the control treatment with BR5 at ATS (**Fig. 9**).

TDM increased progressively over time due to the interaction between nitrogen management and varieties from ATS to the MS. At MS, the highest TDM (75.14 g $hill^{-1}$) was observed with the combination of T4 treatment in BR5, which was statistically like the combination of T_5 treatment. The lowest TDM (3.18 g $hill^{-1}$) was recorded in the control treatment with BRRI dhan34 at ATS (**Fig. 10**).

The CGR was significantly influenced by the interaction between nitrogen management and variety across most growth stages, except between the BS and FS. The uppermost CGR (28.12 g $m^{-2}day^{-1}$) was seen in FS to MS with the combination of T5 in BR5. The lowest CGR (0.51g $m^{-2}day^{-1}$) occurred in the control treatment with BRRI dhan34 from ATS to MTS (**Fig. 11**).

The highest RGR of 0.17 g $g^{-1}day^{-1}$ was achieved in BRRI dhan70 with the T_4 treatment. This RGR was statistically like that observed with the BRRI recommended N dose and the combinations of T_5 treatment for the same variety between the MTS and BS. In contrast, the minimum RGR (0.01 g $g^{-1}day^{-1}$) was observed in the control treatment with BRRI dhan34, which was statistically comparable to the RD of N and various other combinations of T_3, T_4 and T_5 treatments in BRRI dhan34 from FS to MS (**Fig. 12**).

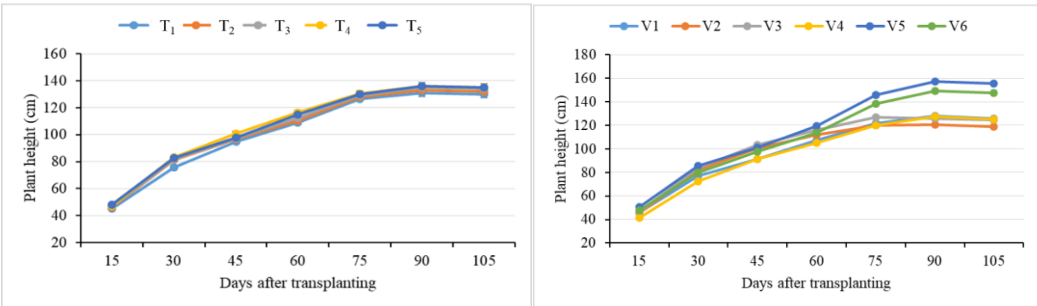

Fig. 1. Effect of INM and variety on PH at various DAT.

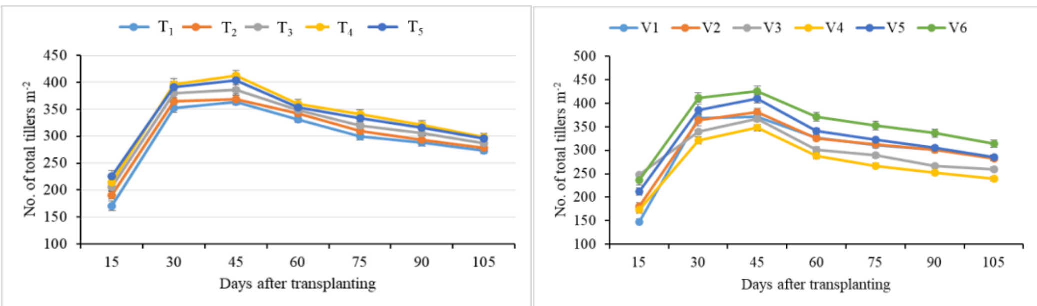

Fig. 2. Impact of INM and variety on NTT m^{-2} at various DAT.

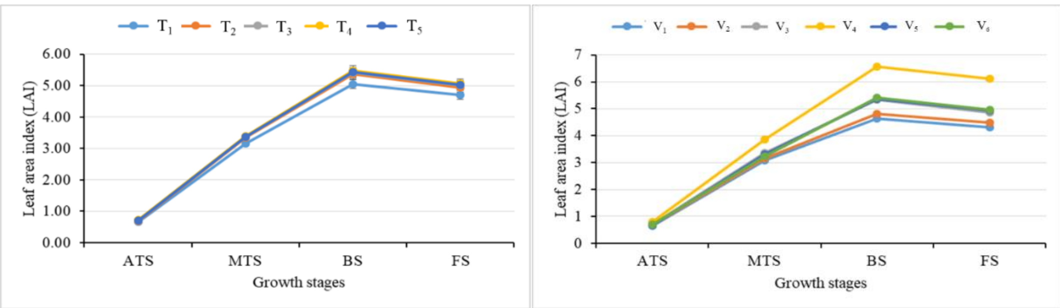

Fig. 3. Impact of INM and variety on LAI at DGS.

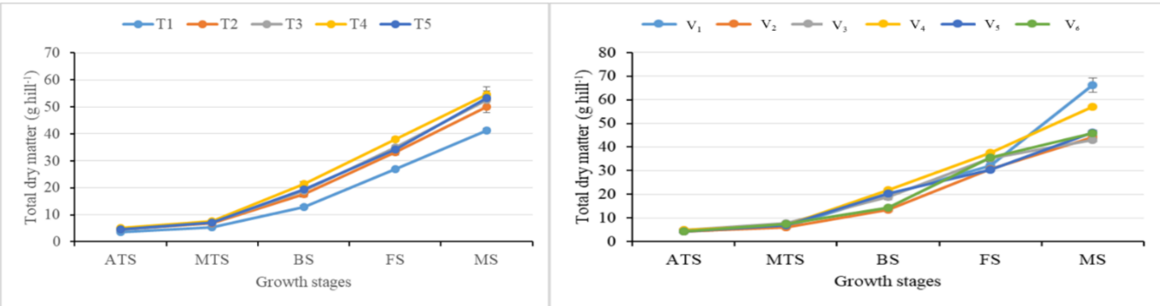

Fig. 4. Impact of INM and variety on total dry matter at DGS.

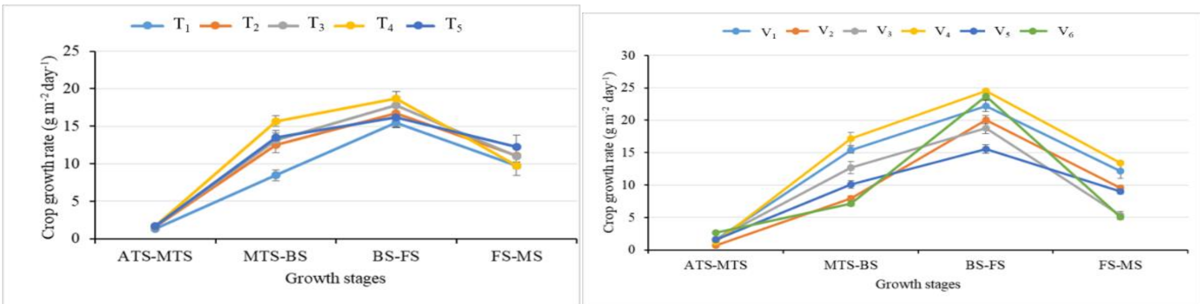

Fig. 5. Impact of INM on crop growth rate at DGS.

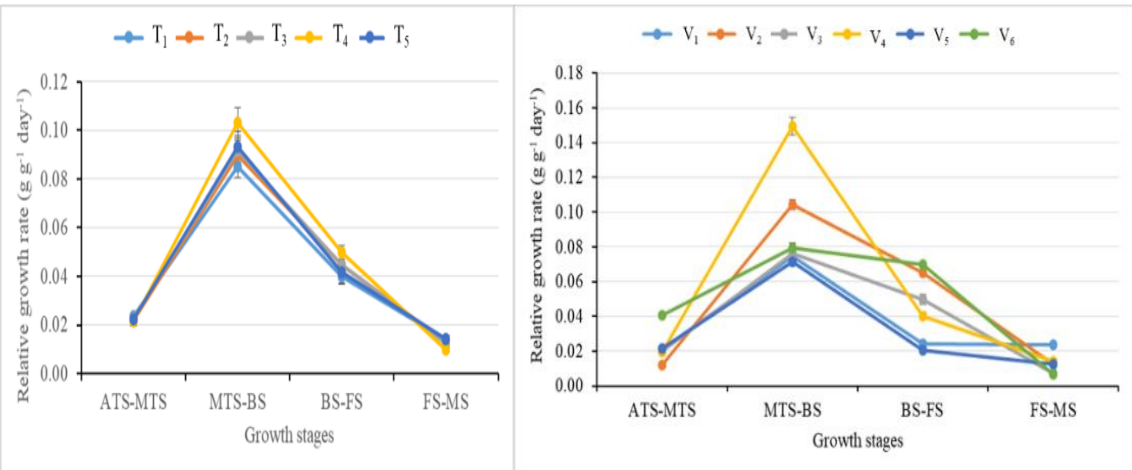

Fig. 6. Effect of INM on relative growth rate at DG.

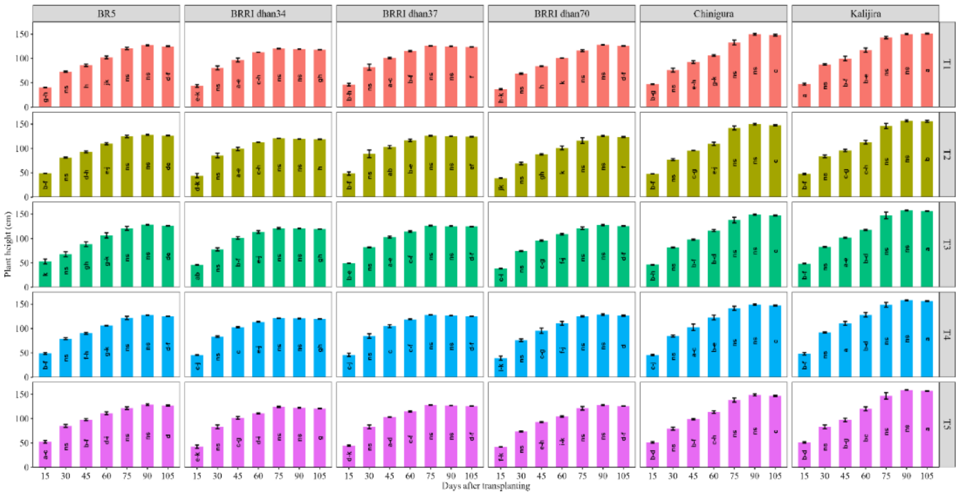

Fig. 7. Interaction impact of INM and variety on PH at different DAT.

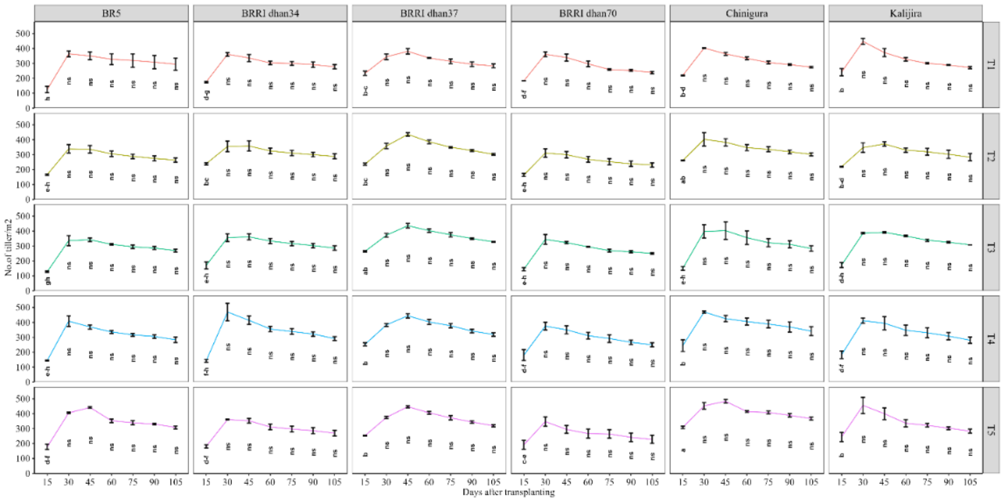

Fig. 8. Interaction impact of INM and variety on NTT m-2 at different DAT.

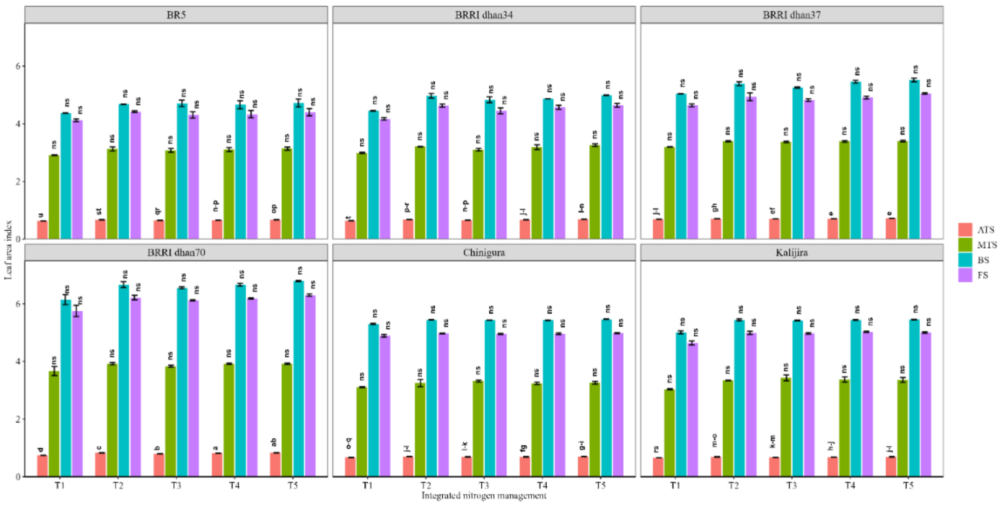

Fig. 9. Impact of INM and variety on LAI at DGS.

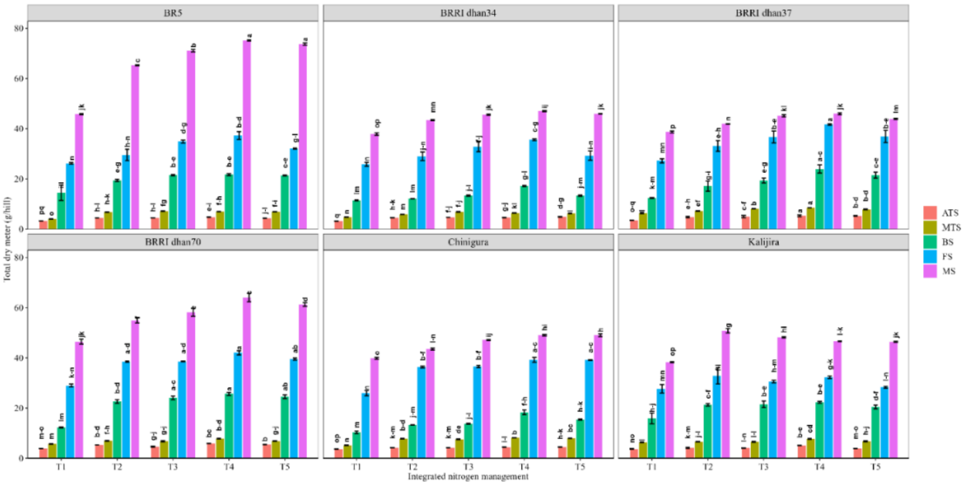

Fig. 10 Impact of INM and variety on total dry matter at DGS.

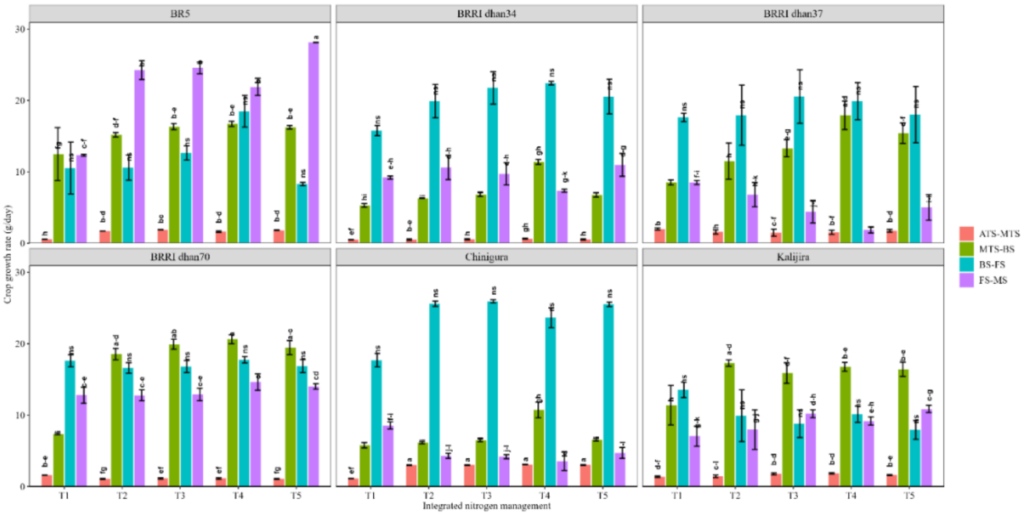

Fig. 11. Impact of INM and variety on crop growth rate at DGS.

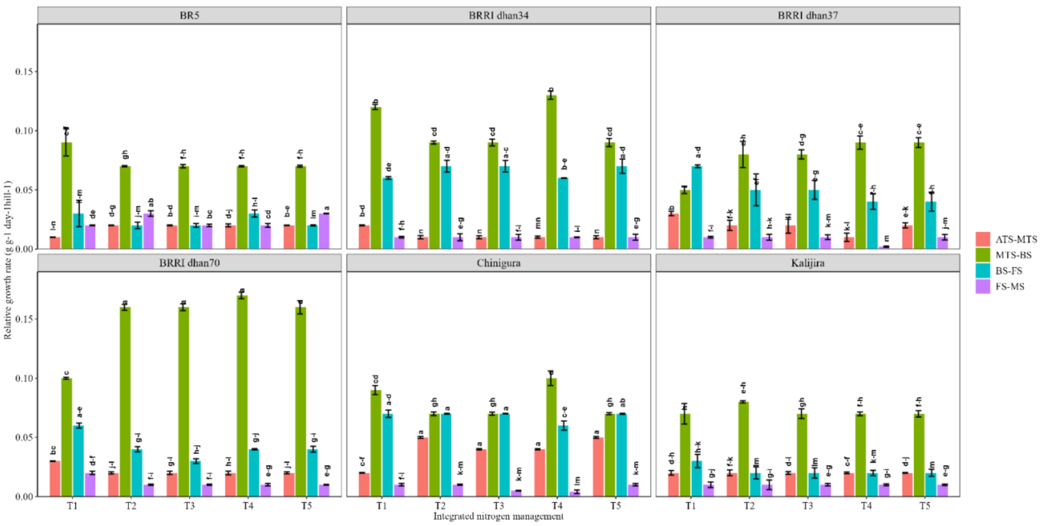

Fig. 12. Impact of INM and variety on relative growth rate at DGS.

Legends: T_1 = Control (No N), T_2 = BRRI Recommended dose of N, T_3 = 70% N from urea + 30% N from cow dung, T_4 = 70% N from urea + 30% N from vermicompost, T_5 = 70% N from urea + 30% N from poultry manure, ATS = Active tillering stage, MTS = Maximum tillering stage, BS = Booting stage, FS = Flowering stage and MS = Maturity stage

PCA visualization of rice yield and yield parameters as impacted by variety and INM

PCA was employed to identify the traits that most effectively describe the influence of variety and INM on yield traits and yield. The first principal component (PC1), which explains 53.5% of the total variance, is plotted along the x-axis, while the second principal component (PC2) accounts for 20.8% of the total variance, is represented on the y-axis (**Fig. 13a and 13b**). In the biplot, the treatments varieties are represented by the data points labeled 1-6 **(Fig. 13a)** and INM labelled 1-4. In the case of variety, TGW and GY have strong positive correlation but TT and PN are negatively related with these variables. In addition, PH and SSPP are positively correlated but HI is negatively related with these variables (**Fig. 13a**). For, INM, GPP, PN, TT, SY, PH, GY, HI and TGW are clustered together indicating they have strong positive correlation with each other, but SSPP is negatively related with these variables (**Fig. 13b**).

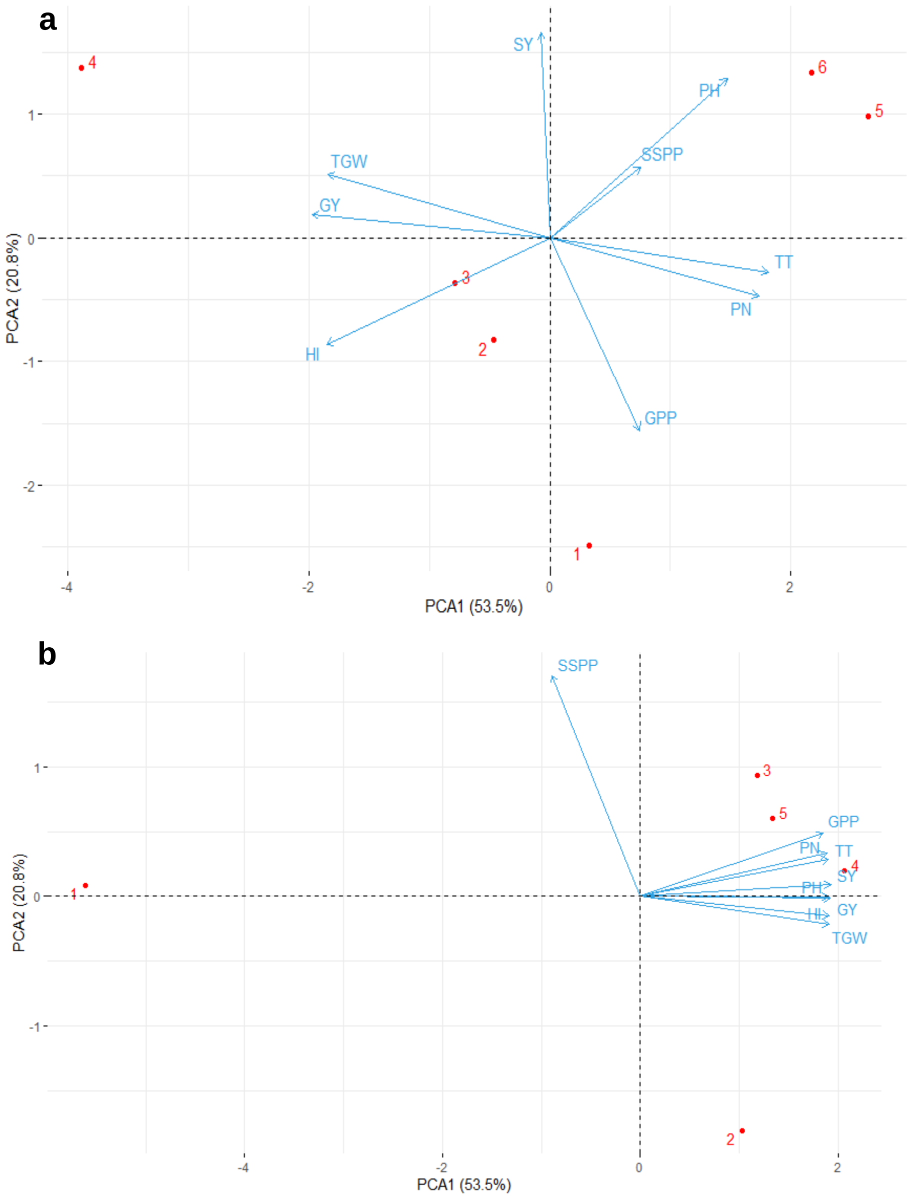

Fig. 13. PCA visualizes rice yield with its contributing traits as impacted by variety (a) and INM (b), wit arrows from centroids indicating dissimilarities. In a vector, the length represents the strength of the variable's contribution, and the angles show the interactions between variables; small angles show strong positcorrelations.

Correlation matrix among rice yield parameters impacted by variety and INM

For each pair of characteristics, the matrix displayed a correlation coefficient that ranged from -1 (completely negative correlation) to 1 (perfectly positive correlation), with 0 signifying no association at all (**Fig. 14 and 15**). For variety, we observe that GY exhibited significant strong positive correlations with HI, and TT with PN. While PH had a significantly strong negative correlation with HI (**Fig. 14**). In the case of INM, SSPP had negative correlation with all yield traits, while except SSPP, all other yield parameters showed significant strong positive correlation with each other's (**Fig. 15**).

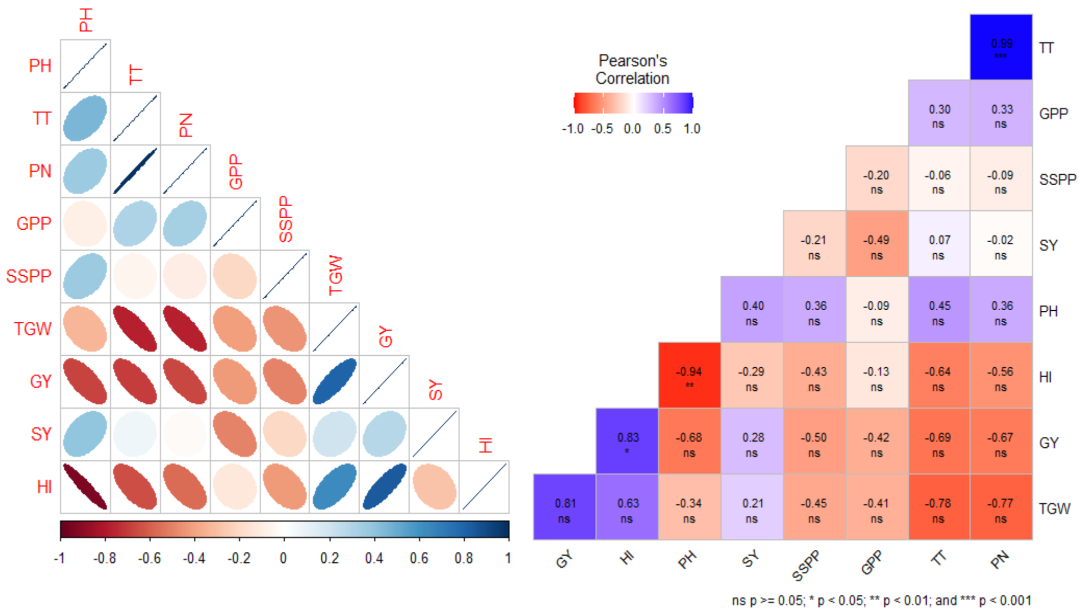

Fig. 14. Variety-influenced correlation matrix for rice yield parameters, blue squares denote positive correlations and red squares negative correlations; the color contrast between blue and red and mat circles indicate strength, which ranges from -1 to +1.

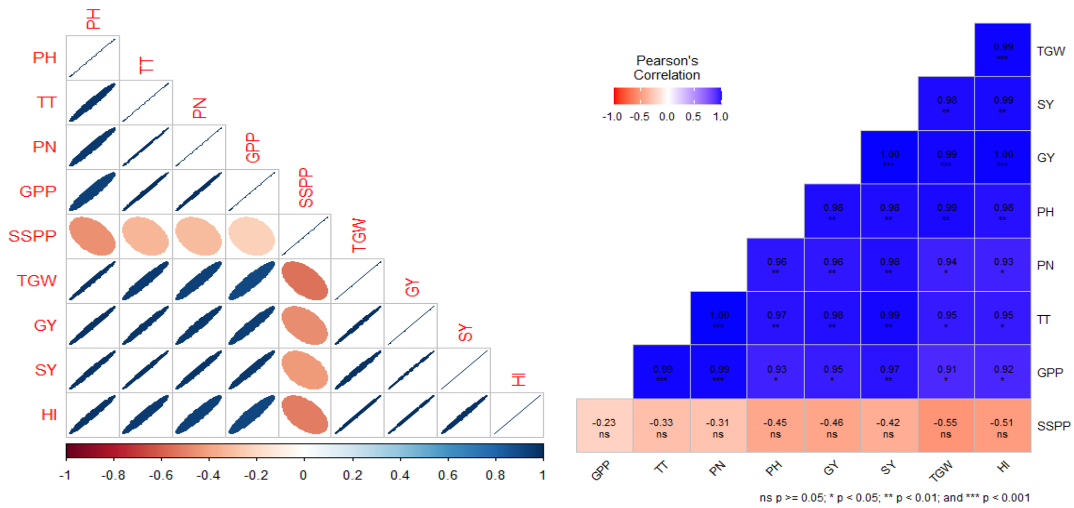

Fig. 15. INM-influenced correlation matrix for rice yield parameters, blue squares denote positive correlations and red squares negative correlations; the color contrast between blue and red and mat circles indicate strength, which ranges from -1 to +1.

Heatmap analysis of rice yield parameters as impacted by Variety and INM

The x-axis illustrates the variables related to yield factors, whereas the y-axis represents the different treatments (**Fig. 16a and 16b**). For variety, GY and TGW, GPP, PH, TT and SY had high contribution with V4, V1, V5, V6 respectively. While the variables TT and PN had low contribution with V_4, and GY and HI had low contribution with V_5 (**Fig. 16a**).

For INM, the variables GPP, TT, PN, PH, SY represented the highest contribution with T_4. Almost all variables had high contributions with T_2, T_3, T_4 and T_5 except SSPP. SSPP has low contribution with T2 and high with T_1. All other parameters had low contribution with T_1 (**Fig. 16b**).

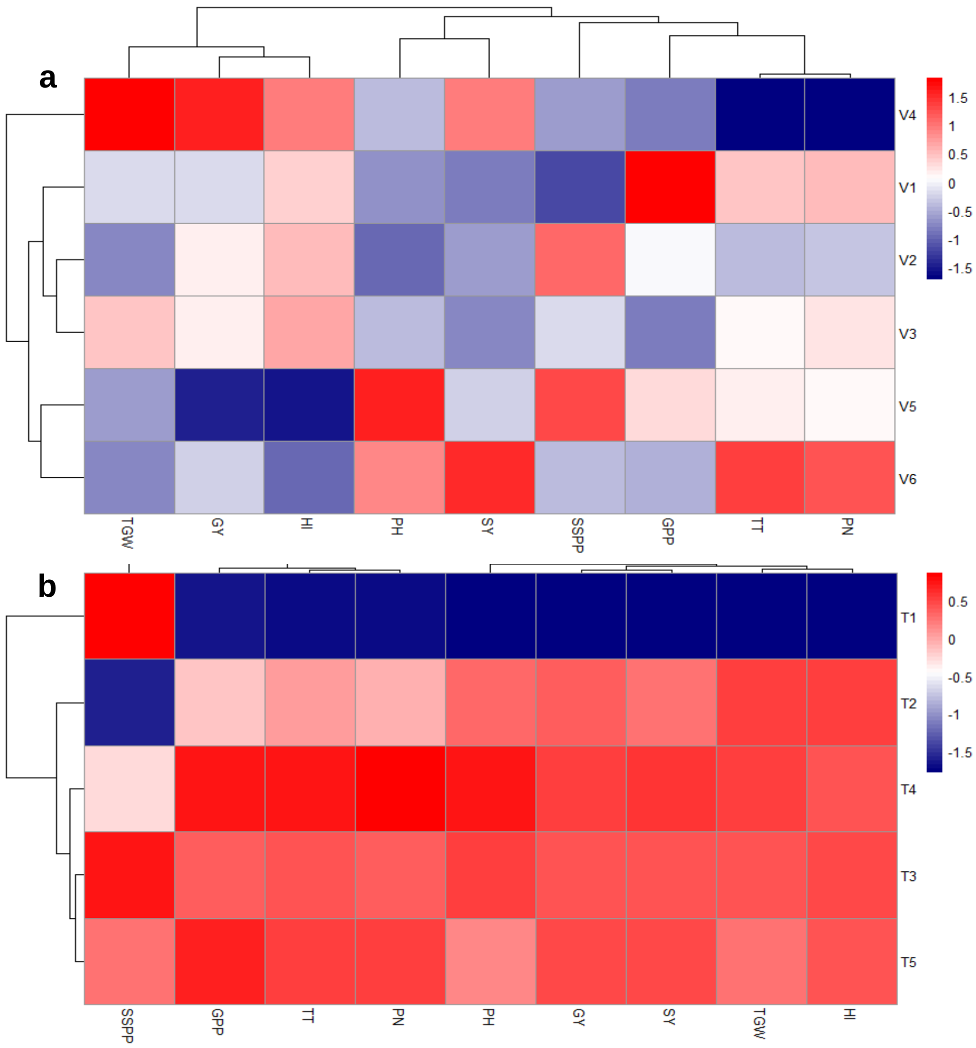

Fig. 16. Rice traits that are affected by variety (a) and INM (b) are clustered hierarchically. Red signifies high and blue low, whereas colors show relative values from -1 to +1.

Discussion:

The tallest PH was achieved with the application of T4 and T5 treatments. All treatments were significantly superior to the control (no N fertilizer). Several researchers have observed similar outcomes with mixed organic manure and chemical fertilizers, indicating their positive effect on rice PH (Kumar et al., 2010; Babar and Dongale, 2011; Singh et al., 2018; Akondo et al., 2024; Ahmed et al., 2025). Typically, modern aromatic rice varieties have a shorter PH than traditional local aromatic varieties, possibly due to genetic differences. PH was significantly influenced by variety, with Kalijira exhibiting the tallest plants at all sampling dates, reaching its maximum at 90 DAT. On the other hand, the lowest plant height was found in BRRI dhan34 in all DAT (Sritarapipat et al., 2014; Ray et al., 2015; Paul et al., 2016; Adebayo et al., 2023; Alam et al., 2024). These results are consistent with the results of PCA and the correlation matrix, which showed that PH and harvest index (HI) had a significantly negative correlation, and the height of the plant might not translate to high-efficiency yields.

INM significantly affected the NTT (m^{-2}). Tillering increased with growth, peaking at 45 DAT, and then decreased at 60 and 105 DAT across all nitrogen management treatments. The maximum NTT (m^{-2}) was recorded with T4 treatment at 45 DAT, whereas the lowest tiller count was observed in the control group at various DATs. A combination of organic and inorganic N sources increased tillering as plants advanced in growth, reaching a maximum around 60 DAT and declining at 75 to 90 DAT due to continuous nutrient supply from vermicompost and inorganic fertilizer. Arif et al., (2025), Ashikuzzaman et al., (2024), Laila et al., (2020) and Islam et al., (2018) similarly observed that INM had a significant impact on the NET hill-1. The variety Chinigura showed the highest NTT m^{-2} at 45 DAT, followed by a decline at 60 DAT, while BRRI dhan70 showed the lowest number of tillers m^{-2} at 45 DAT. A similar trend in tiller production, increasing from 15 to 45 DAT and decreasing afterward, was also reported by Dola et al., (2024). PCA analysis further revealed a negative correlation between NTT and NGP, emphasizing the complex interaction among yield traits.

Nitrogen management and variety both significantly influenced LAI at various growth stages. In terms of nitrogen management, the highest LAI was achieved with T4 treatment at the BS, and the least LAI was observed in the control at the ATS. Nutrient management substantially impacts LAI, which increases as plants age up to the booting stage and subsequently declines. The highest LAI was noted in BRRI dhan70 at BS, whereas BR5 had the lowest at ATS. Hossain et al., (2024) and Islam et al., (2024) found that BRRI dhan34 had the highest LAI at 70 DAT, while BRRI dhan37 showed the lowest at the same stage, which aligns with findings by Mia and Shamsuddin (2011).

TDM production increased with plant age until flowering, after which it declined across nitrogen management treatments. The maximum TDM was observed at the MS stage with T4 Treatment, while the lowest TDM was recorded in control at ATS. Kirttania et al., (2013), Paul et al., (2014), Marzia (2015), Nila et al., (2018), Mim et al., (2024) and Hussein and El-Dediny, (2025) have reported similar trends in TDM, with a slow initial increase that accelerates and peaks at 85 DAT. In terms of variety, BR5 displayed the highest TDM at MS, while BRRI dhan37 had the lowest. Studies by Mostofa et al., (2024) indicate that dry matter production initially increases slowly, then accelerates with time, peaking in the later stages of crop development.

CGR initially increased over time, reaching its peak from BS to the FS before declining from FS to MS. The application of T4 treatment resulted in the highest CGR, followed by the BRRI RD of N, T3, and T5 treatment from BS to FS. The least CGR was found in control from ATS to the MTS. The higher CGR observed in modern varieties may be due to a higher LAI, as demonstrated by Noreldin et al., (2024), Pal et al., (2024) and Nur-A-Alam et al., (2024) who found that CGR decreases from panicle initiation to flowering due to leaf senescence. The highest CGR was recorded in BRRI dhan70 from BS to FS, while Kalijira had the lowest from ATS to MTS.

RGR declined progressively with crop age and remained unaffected by different organic nitrogen sources. The highest RGR was recorded at MTS to BS with T4 treatment, while the least was found in control treatment from FS to MS. According to Rao et al., (2013), Rahman et al., (2024) and Soliman (2025), plant growth variation due to organic manure application is influenced by nutrient availability and release patterns. The variety BRRI dhan70 recorded the highest RGR from MTS to BS, while Chinigura, followed by BRRI dhan34, BRRI dhan37, and Kalijira, had the lowest from FS to MS.

Various nitrogen sources significantly influenced crop attributes, yield-contributing traits, and yield, except for sterile spikelets per panicle (NSS panicle^{-1}). The highest PH, NTT (m^{-2}), NP m^{-2}, TGW, GY, and SY were recorded with T4 treatment, while the least values were in control. PCA biplot also supported strong positive correlations between TGW and GY, underlining the importance of grain weight in productivity. Increased nitrogen levels enhanced plant height in varieties like Basmati, which promotes succulence in plants (Sidhue et al., 2004). Rahman et al., (2008) observed similar responses in PH with nitrogen application. Variation in NTT and NET hill-1 due to nitrogen management likely resulted from the continuous nutrient supply by vermicompost and inorganic fertilizers (Islam et al., 2016; Laila et al., 2020; Tonni et al., 2024 and Srity et al., 2024).

The highest NET m^{-2} was recorded with T4 treatment, whereas the least was in control. The combining chemical fertilizers with organic manures led to a higher panicle count hill-`, consistent with findings by Khan and Shoumik (2022), who reported that higher N levels encouraged NP formation. Combined applications of organic and inorganic fertilizers significantly influenced NGP, as documented by Jahan et al., (2017). TGW increased with higher N sources, as reported by Kumar et al., (2010), and balanced applications of chemical fertilizers and organic manures positively impacted aromatic rice GY. The synergistic application of organic and inorganic fertilizers also had a positive influence on the SY of fine rice. HI varied with nitrogen management, with the highest values recorded in treatments with the recommended nitrogen dose and the lowest in control, indicating that increased fertilizer rates can enhance biological yield, as more biomass is produced, contributing to a higher HI (Jahan et al., 2017; Zinnat et al., 2024).

Varietal differences significantly affected crop attributes, yield-contributing traits, and yield. Generally, modern aromatic varieties have shorter plant heights than traditional varieties. The differences in PH, NTT m^{-2}, NGP, TGW, and GY among varieties may be attributable to genetic factors. Kalijira consistently exhibited the tallest PH, while BRRI dhan34 had the shortest across sampling dates. Chinigura recorded the highest NTT m-2, while BRRI dhan70 had the lowest. Traditionally aromatic cultivars produced more tillers but yielded less, while modern varieties had fewer tillers but higher yields. Consequently, tiller number did not play a critical role in aromatic rice yield (Hossain and Alam, 1991). Variation in NTT and NET hill-1 among varieties has also been reported by Ali et al., (2018), with Chinigura producing the highest NP m^{-2} and BRRI dhan70 the lowest.

BR5 recorded the highest NGP, while BRRI dhan37 had the lowest. Panicles with short, bold grains tended to have higher grain density, while those with medium and long grains were sparser. NGP is considered one of the most critical factors for maximum yield in rice cultivars (Venkateswarlu et al., 1986). Kalijira showed the highest NSS panicle-1, while BR5 recorded the lowest. Kalijira has the highest NSS panicle-1. TGW varied among varieties due to grain size, which is crucial for yield determination (Rahman et al., 1996). Among the six aromatic varieties tested, BRRI dhan70 achieved the highest GY, while Kalijira produced the lowest. Adhikari et al., (2018) and Uppu and Shiv (2019) also found that aromatic fine rice GY was significantly influenced by variety. Chinigura achieved the highest SY due to taller plant height and more tillers, while BR5 recorded the lowest. The highest HI was recorded in BRRI dhan70, and the lowest in Kalijira, aligning with Priyadarsini's (2001) findings. The traditional variety Chinigura showed the highest SY, suggesting efficient translocation and mobilization of photosynthates into grains. HI was positively correlated with yield (Yoshida 1983; Manir et al., 2025).

The interaction between nitrogen management and variety significantly impacted yield-contributing attributes and yield, except for total tillers m^{-2}, NP m^{-2}, and NSS panicle-1. The tallest plant was recorded with T4 treatment in Kalijira, while the shortest was observed in the control treatment with BRRI dhan34. The highest NGP was found in BR5 with T4 treatment, statistically like treatments with T5 treatment, while the lowest was found in the control with Chinigura. TGW was highest in BRRI dhan70 with the BRRI RD, comparable to T5 treatment, and lowest in control with Chinigura. GY was highest in BRRI dhan70 with T4 treatment, followed by other treatments with RD, and lowest in Kalijira under the control. These findings reflect earlier PCA results highlighting the strong relationship between TGW and GY. Chinigura yielded the highest SY with T4 treatment, comparable to cow dung and poultry manure treatments and the BRRI RD with BRRI dhan70 and Chinigura, while BR5 had the lowest SY in control. The highest HI was recorded with the BRRI RD in BRRI dhan70, followed by T3, T4 and T5 treatment, with the lowest in Chinigura under control treatment (Manir et al., 2025).

Conclusion:

The current study indicates that modern aromatic rice varieties exhibited higher values for LAI, TDM, and CGR when 70% of the RD of Nitrogen was applied from urea and 30% from vermicompost. In contrast, local aromatic varieties showed superior values for Relative Growth Rate (RGR), yield-contributing traits, and overall yield, with no clear distinction between the two varieties in terms of yield. Local varieties had the highest plant height, NTT, NP (m^2), NGP, and SY. However, the highest GY was observed in the modern variety BRRI dhan70 under the specified N management. The inclusion of vermicompost within the nitrogen management system highlights the sustainability benefits of Integrated Nutrient Management (INM), as it reduces dependence on chemical fertilizers, improving soil health and supporting long-term agricultural practices. Based on the findings, it is recommended that farmers consider incorporating vermicompost in their nitrogen management practices to enhance both yield and sustainability, while reducing the environmental impact of chemical fertilizer use.

Consent for publication:

All authors have given their consent for publication.

Author contribution:

Conceptualization: M.P.A., M.A.S., and M.R.U.; methodology, data collection and original data analysis: M.R.M., M.A.A., and M.T.A.; data presentation, writing: M.R.M., M.T.A, U.K.S., and M.S.I; reviewing and editing: M.P.A., M.A.S., and M.R.U.; funding acquisition: M.R.U. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest:

The author confirms the absence of any conflicts of interest.

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