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IMPACT OF VARIABLE NITROGEN LEVELS ON GROWTH DYNAMICS, DRY MATTER PARTITIONING, AND YIELD OF RICE

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Abstract

Nitrogen availability in soils strongly influence rice growth and plays a critical role in rice yield. The present study was conducted at the research field of the Bangladesh Rice Research Institute (BRRI), Gazipur to evaluate the effects of different nitrogen levels on growth dynamics and dry matter partitioning of rice varieties. The experiment was laid out in randomized complete block design with two factors *viz.*, six nitrogen levels (N_0, N_{40}, N_{80}, N_{120}, N_{160} and N_{200}) and two rice varieties (BRRI dhan28, BRRI dhan29), comprising 12 treatment combinations. Forty days' old seedling were transplanted with the planting geometry of 20 cm × 20 cm. Nine plants were randomly sampled from each plot at 15-day intervals to record dry matter production, growth parameters, grain yield, and yield-contributing traits. Results showed that higher nitrogen levels, particularly N_{160} and N_{200}, produced the maximum dry matter accumulation in leaf, culm, and panicle at all growth stages. Growth parameters such as leaf area index (LAI), crop growth rate (CGR), and net assimilation rate (NAR) peaked at 75–90 days after transplanting. The grain yield was was strongly associated with total dry matter production. Overall, the study demonstrates that nitrogen application at 160–200 kg N ha^{-1} optimizes growth dynamics, dry matter partitioning, and grain yield of BRRI dhan29 and BRRI dhan89, highlighting the importance of adequate nitrogen management for maximizing rice productivity.

Keywords: Dry matter, Crop growth rate, Leaf area index, Net assimilation rate, Nitrogen levels

1. Introduction

Rice (Oryza sativa L.) is the primary dietary staple for nearly 50% of the world's population and supplies about 35%–60% of the dietary calories for more than three billion people, highlighting its global importance for food security (Amanullah *et al.*, 2016). With rapid population growth and economic development, the demand for rice continues to rise, posing serious challenges to sustainable rice production worldwide (Zhu *et al.*, 2023; Islam *et* *al.*, 2024). Rice growth and yield are governed not only by genetic potential but also by efficient dry matter production and its partitioning among different plant organs during various phonological stages, which is largely determined by source–sink relationships.

Among the various growth-limiting factors, nutrient availability plays a crucial role, with nitrogen (N) being the most critical and yield-limiting nutrient in rice cultivation (Hasnat *et al.*, 2022). These challenges are more pronounced in diverse agro-ecological zones, particularly for long-duration rice varieties grown under rained and irrigated ecosystems. Rice requires higher nitrogen input compared to other nutrients, as nitrogen regulates vegetative growth, tillering, leaf area development, and overall biomass accumulation. Although atmosphere contains about 78% nitrogen which is not directly available to rice plants (Vijayakumar *et al.*, 2022; Alam *et al.*, 2023). Excessive application of nitrogen fertilizers can deteriorate soil health by inducing soil acidification and nitrogen losses, while insufficient nitrogen supply restricts photosynthesis, dry matter accumulation, and ultimately grain yield (Nayak *et al.*, 2020; Saudy *et al.*, 2023). Since nitrogen remains the most yield-limiting nutrient in lowland rice systems worldwide (Fageria *et al.*, 2001), understanding the impact of variable nitrogen levels on growth dynamics, dry matter partitioning, and yield of rice varieties is essential for developing efficient and sustainable nitrogen management strategies.

The efficiency of the Urea-N in rice field is very low, generally around 30–40%, in some cases even lower (Choudhury *et al.*, 2005; Al-Amin *et al.*, 2025). Low efficacy of nitrogenous fertilizer is attributed mainly to ammonia volatilization, denitrification, leaching, and runoff losses (Cho 2003; Freney *et al.* 1990). The losses of N depend on environmental conditions and different management practices. Besides, imbalanced application of nitrogen can disrupt assimilate partitioning and reduce sustainable yield. Balanced nitrogen fertilization increases dry matter accumulation at flush, dry matter accumulation from flush to maturity, translocation rate and yield (Qin x *et al.*, 2025). For the enhancement of nitrogen use efficiency require the increment of N uptake, utilization and harvest index which involves many crops physiological mechanisms and agronomic characters. Nitrogen is involved in all the metabolic processes in plants and about 75% of leaf N is associated with chloroplast, which are essential for dry matter production during photosynthesis (Mae, 1997). Moreover, nitrogen is the important source to increase the dry matter production which ultimately partitioned into the grain yield. Therefore, the present study was undertaken to investigate the effect of variable nitrogen levels on dry matter partitioning and growth responses in two long-duration rice varieties.

2. Materials and Methods

2.1 Experimentation

The experiment was conducted at Bangladesh Rice Research Institute (BRRI) Farm, Gazipur (23°85.9′ N and 90°82.4′ E), Bangladesh, during Boro rice season, 2022. Two long-duration rice varieties, BRRI dhan29 and BRRI dhan89 were evaluated under six nitrogen levels: N_0, N_{40}, N_{80}, N_{120}, N_{160} and N_{200}. The experiment was arranged in a randomized complete block design with three replications. The recommended doses of other fertilizers (P–K–S–Zn) were applied at rates of 12–60–10–1 kg ha^{-1}, respectively. All fertilizers were applied as a basal dose, except nitrogen, which was top-dressed in three equal splits. Forty-day-old seedlings were transplanted in January 2022 with a spacing of 20 cm × 20 cm.

2.2 Soil sampling and analysis

Before the experiment, soil samples were collected from a depth of 0–15 cm in the experimental field. The samples were air-dried, ground, and passed through a 2-mm sieve, then stored in plastic containers for physico-chemical analysis. Soil properties were determined following standard procedures (Page *et al.*, 1982). The experimental soil was clay loam in texture, slightly alkaline (pH 6.7), non-saline (ECe 1.02 dS m^{-1}), and moderately fertile, containing 1.18% organic carbon, 0.15% total nitrogen, 0.13 meq 100 g^{-1} exchangeable potassium, 14 mg kg^{-1} available sulfur, and 1.5 mg kg^{-1} available zinc.

2.3 Data recording and handling

Nine plants were taken randomly from each plot as representative sample for dry matter production and other growth parameter data mostly at 15 days' interval after transplanting. The samples were cleaned, separated into leaves, culm and panicle and then oven-dried at 70 ºC until a constant weight is obtained and dry weight of leaves, culm and panicle were recorded separately in gm-^{2}. Total dry weight was calculated as the sum of dry weights of the plant components. At harvest yield data were recorded. Physiological growth parameters were calculated using successive sampling data following the methods described by Watson (1952)

$$Leaf\ area\ index\ (LAI) = \frac{Leaf\ Area\ (A)}{Ground\ Area\ (P)}$$

$$Crop\ growth\ rate (CGR) = \frac{W2-W1}{P(T2-T1)} g\ m^{-2} day^{-1}$$

Where,
W_1 = Dry weight of plant m^{-2} at time T_1
W_2 = Dry weight of plant m^{-2} at time T_2
P = Ground area (m^{2})
T_1 and T_2 are the two consecutive time period

$$Relative\ growth\ rate\ (RGR) = \frac{LnW2-LnW1}{T2-T1} g\ g^{-1} day^{-1}$$

Where,
W_1 = Dry weight of plant m^{-2} at time T_1
W_2 = Dry weight of plant m^{-2} at time T_2
Ln = Natural log

T_1 and T_2 are the two consecutive time period

$$Net\ assimilation\ rate\ (NAR) = \frac{W2 - W1}{T2 - T1} \times \frac{1}{LA}$$

Where,
W_1 = Dry weight of plant m^{-2} at time T_1
W_2 = Dry weight of plant m^{-2} at time T_2
T_1 and T_2 are the two consecutive time period
LA= Leaf area

2.4 Statistical analysis

Data were analyzed using RStudio version 4.0. Factorial ANOVA was performed to evaluate the effects of rice varieties, nitrogen levels, and their interaction on growth parameters at different growth stages. Treatment means were compared using the Critical Difference (CD) test at a 5% level of significance. Graphical representations of the results were prepared using Microsoft Excel 2010.

3. Results and Discussion

3.1 Dry matter accumulation

Dry matter accumulation is important factor for grain yield production. The enhancement of rice yield potentiality might come from the increased dry matter production. Total dry matter production varied significantly due to the effect of N-levels at different growth stages. Total dry matter production (TDM) increased progressively with the increase of growth stages and N-levels. At 30 DAT the highest culm dry matter was obtained with $N_{80,}$ N_{160} and N_{200}. However, Culm dry matter at N_0, N_{40} and N_{120} level was similar. At nitrogen level N_{80}, N_{160} and N_{200} leaf dry matter production was highest. At 60 DAT, culm and leaf dry matter production was higher in N_{200} followed by N_{160} than other treatment. However, leaf dry matter was the lowest at N_0 followed by N_{40} level. At 75 DAT the highest culm dry matter was obtained with N_{160} and N_{200}. Leaf dry matter was highest under the treatment $N_{200.}$ At nitrogen level N_0 lowest culm and leaf dry matter was observed. Leaf and culm dry matter was similar at nitrogen level N_{80} and N_{120} at this stage. At this stage panicle weight was higher in the treatments with N_{80} nitrogen level. However, lowest panicle weight was obtained with nitrogen level $N_{120.}$ At 90 DAT leaf, culm, and panicle dry matter production were significantly higher under N_{160} and N_{200} nitrogen levels, indicating enhanced biomass accumulation at higher nitrogen supply. At 105 DAT leaf and culm dry matter production declined across all treatments due to leaf senescence while panicle dry weight was similar at this stage except the treatment without nitrogen. The rapid growth of dry matter at the higher nitrogen level may be due to the robust growth and increased leaf area development of plants (Fig. 1).

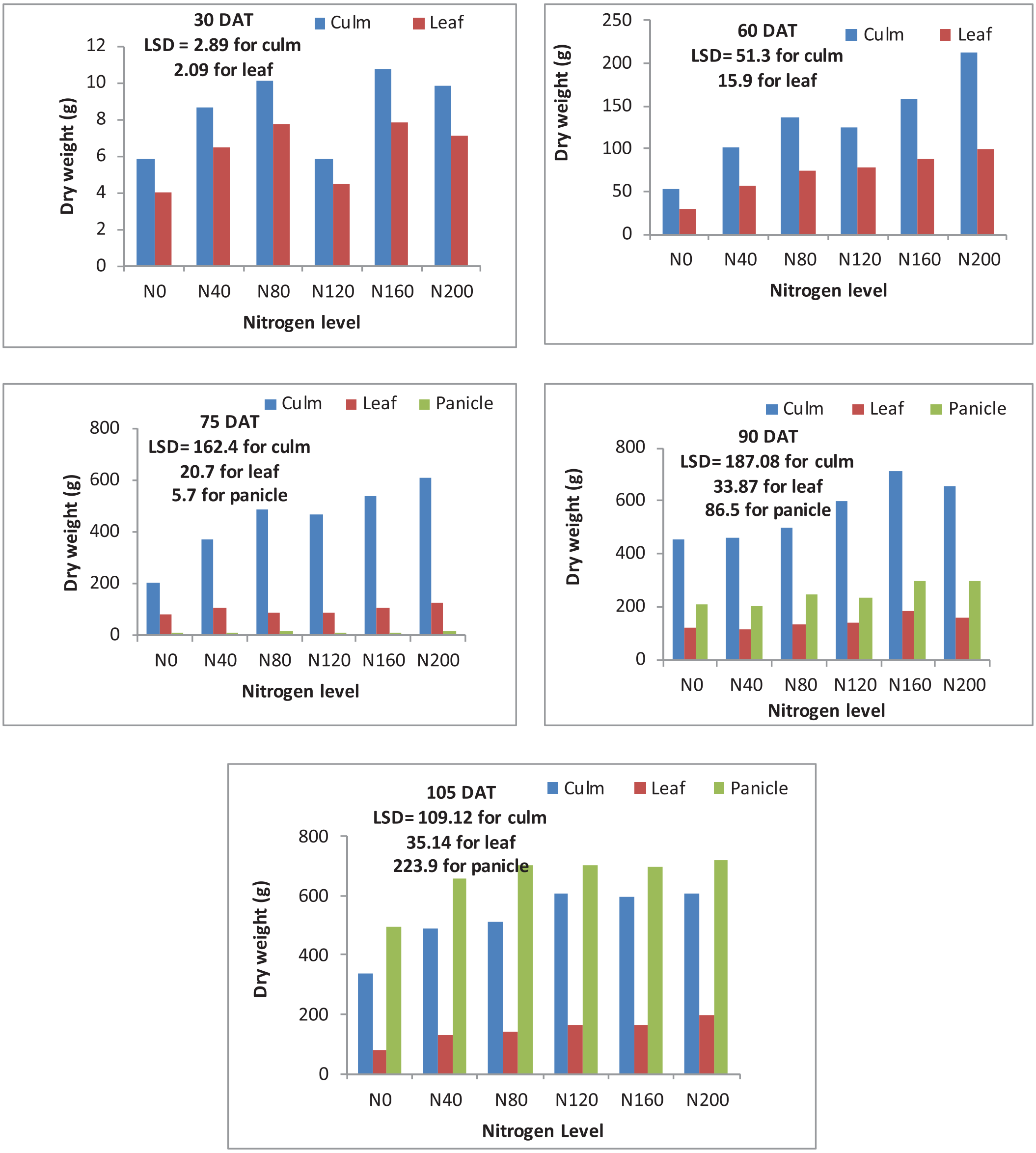

Fig.1 Dry matter partitioning (g/m^2) in rice at different days after transplanting

3.2 Correlation studies of TDM with grain yield

It is stated that total dry matter production at 60 DAT, 75 DAT, 90 DAT and 105 DAT were positively correlated with the grain yield of the tested rice varieties which indicates that grain yield was greatly influenced by total dry matter production (Fig. 2).

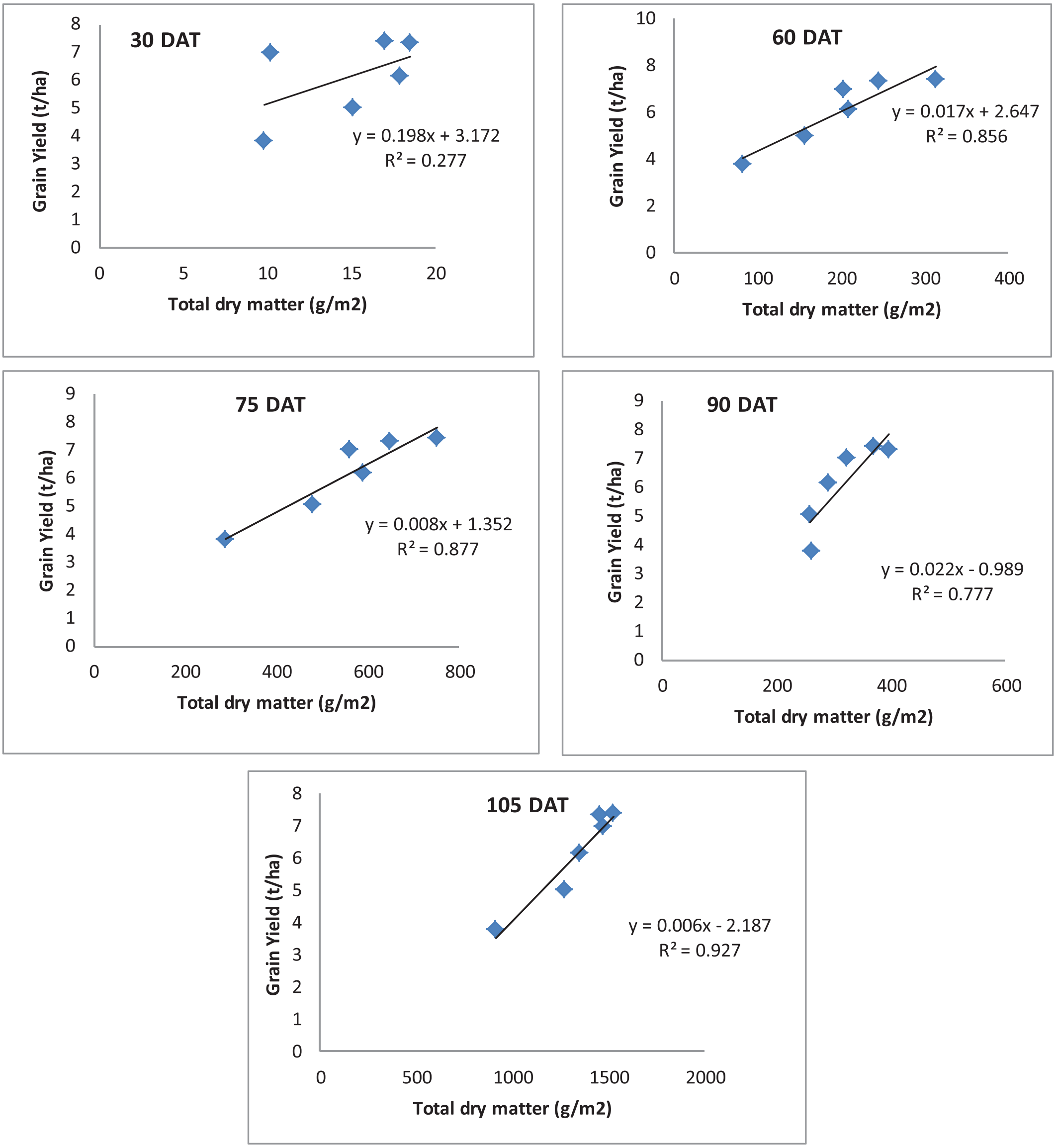

Fig.2 Relationship between total dry matter production and grain yield in rice at different days after transplanting

3.3 Leaf area index

Leaf area index is important physiological parameters which accounts for the production of photosynthate and finally determines crop yield because it influences the light interception by the crop canopy (Fageria *et al.*, 2008). Interaction effect of variety and nitrogen level for leaf area index was insignificant. The average leaf area index (LAI) of the rice increased gradually up to 60 DAT and thereafter it increased sharply reaching a peak value at 90 DAT that is heading or flowering, but there after it decreased gradually towards maturity due to senescence of leaves. The LAI of rice increases as crop growth advances and reaches a maximum at about heading or flowering (Yoshida, 1981). Leaf area index was higher in nitrogen level N_{120}, N_{160} and N_{200} at 30 DAT, 75 DAT and 90 DAT irrespective of varieties. At maturity stage N_{200} produced the highest leaf area index. Higher leaf area index may be due to the higher number of leaves and increased leaf area. (Navinkumar *et al.*, 2018) also reported that the higher LAI was associated with the increased tiller production and size of the leaves (Table 1).

Table 1. Leaf area index of rice as influenced by varieties and nitrogen levels at different DAT

Treatments	Leaf area index (LAI)				
	30 DAT	60 DAT	75 DAT	90 DAT	105 DAT
Varieties					
V1-BRRI dhan29	0.05	0.87	1.42	1.68	1.09
V2-BRRI dhan89	0.06	0.86	1.41	1.51	0.59
S.E. (±)	0.01	0.71	0.11	0.11	0.16
CD. at 5%	NS	NS	NS	0.22	0.01
Nitrogen (N) (kg/ha)					
N_0	0.03	0.32	1.12	1.21	0.54
N_{40}	0.05	0.65	1.37	1.26	1.00
N_{80}	0.02	0.92	1.54	1.65	0.98
N_{120}	0.07	1.05	1.37	1.96	1.07
N_{160}	0.08	0.91	1.48	1.53	1.09
N_{200}	0.06	1.33	1.62	1.98	1.45
S.E. (±)	0.017	1.23	0.20	0.19	0.28
CD. at 5%	0.035	NS	0.41	0.39	0.59
Interaction (V × N)					
S.E. (±)	0.024	2.46	0.28	0.27	0.40
Significance level (5%)	NS	NS	NS	NS	NS

3.4 Crop growth rate

Insignificant interaction was present between variety and nitrogen level for this trait. Crop growth rate was very minimum at the initial stage as 0-30 DAT which increased gradually towards the growth stages. It reached to peak at flowering stage and then decreased gradually to 90-105 DAT as harvest. Higher crop growth rate was obtained with nitrogen level N_{120}, N_{160} and N_{200} at 0-30 DAT. At 30-60 DAT and 60-75 DAT highest crop growth rate was observed in N_{160} and N_{200} nitrogen level. However, at 90-105 DAT highest CGR was found in N_{160} and N_{200} followed by N_{80} and N_{120}. Higher CGR may be due to the higher LAI produced by this nitrogen level. The mean crop growth rate (CGR) was slow between 0-30 DAT, then increased linearly between 30-60 DAT, thereafter increasing slowly between 60 and 90 DAT and finally it decreased sharply towards harvest. Lower CGR in the initial growth stage appears to be mainly due to low leaf area, while higher CGR at flowering and grain development stages may be due to higher LAI and decrease in CGR towards maturity may be attributed to decrease in leaf area as a result of senescence of leaves (Sridhar *et al.*, 2019) (Table 2).

Table 2. Crop growth rate of rice as influenced by varieties and nitrogen levels at different DAT

Treatments	Crop growth rate (g m^{-2} day^{-1})				
	0-30 DAT	30-60 DAT	60-75 DAT	75-90 DAT	90-105 DAT
Varieties					
V1-BRRI dhan29	0.46	6.28	22.4	28.03	23.42
V2-BRRI dhan89	0.52	6.20	23.3	26.77	26.45
S.E. (±)	0.04	0.58	3.00	4.76	7.53
CD. at 5%	NS	NS	NS	NS	NS
Nitrogen (N) (kg/ha)					
N_0	0.33	2.42	13.8	27.03	8.84
N_{40}	0.50	4.73	21.4	28.15	19.8
N_{80}	0.34	6.42	23.5	29.94	22.53
N_{120}	0.59	6.44	23.7	37.90	22.78
N_{160}	0.61	7.58	26.7	32.84	25.94
N_{200}	0.56	9.86	28.2	32.84	25.30
S.E. (±)	0.07	1.00	5.20	13.05	8.25
CD. at 5%	0.14	2.06	10.73	NS	17.02
Interaction (V × N)					
S.E. (±)	0.11	1.43	7.36	11.66	18.46
Significance level (5%)	NS	NS	NS	NS	NS

3.5 Net assimilation rate (NAR)

NAR is the increase in plant dry mass per unit leaf area per unit time. According to Sun *et al.*, 1999 NAR is the rate of photosynthesis minus respiration losses. It is the physiological potential for converting the total dry matter into grain yield. The interaction effect of variety and nitrogen level was not significant. Significant influence of nitrogen level was only observed for net assimilation rate at 0-30 DAT and 75-90 DAT. At 0-30 DAT and 75-90 DAT highest NAR was observed in N_{120} nitrogen level followed by N_{160} and N_{200}. NAR was low at initial growth stage that is 0-30 DAT. Then it increased linearly up to 75-90 DAT. Finally, it dropped to maturity that is 90-105 DAT for all treatments. The Higher NAR with the growth stages was due to higher LAI and dry matter production with those stages (Willians *et al.*, 1946) (Table 3).

Table 3. Net assimilation rate of rice as influenced by varieties and nitrogen levels at different DAT

Treatments	Net assimilation rate (mg^{-2} day^{-1})				
	0-30 DAT	30-60 DAT	60-75 DAT	75-90 DAT	90-105 DAT
Varieties					
V1-BRRI dhan29	1.0	0.7	1.6	1.6	1.0
V2-BRRI dhan89	0.9	0.8	1.6	2.2	1.0
S.E. (±)	1.0	1.0	1.0	1.0	1.0
CD. at 5%	2.0	NS	NS	2.0	NS
Nitrogen (N) (kg/ha)					
N_0	0.7	0.7	1.2	1.2	0.6
N_{40}	0.9	0.7	1.5	1.5	1.8
N_{80}	0.8	0.7	1.6	1.4	1.6
N_{120}	1.0	0.6	1.7	1.9	1.0
N_{160}	1.0	1.0	2	1.7	1.5
N_{200}	1.0	0.7	1.7	3.9	0.9
S.E. (±)	1.0	1.0	1.0	1.0	1.0
CD. at 5%	2.0	NS	NS	2.0	NS
Interaction (V × N)					
S.E. (±)	1.0	1.0	1.0	2.0	1.0
Significance level (5%)	NS	NS	NS	NS	NS

3.6 Relative growth rate

The rate at which a plant incorporates new material of dry matter accumulation into its sink is measured by RGR and is expressed in g g^{-1} day^{-1}. Insignificant interaction effect of variety and nitrogen level was observed for this trait. RGR was maximum at 30-60 DAT and then it was decreased gradually towards growth stages and become very low to maturity stage that is 90-105 DAT. Respiration depends on total biomass, but photosynthesis depends only on photosynthetic biomass, so biomass builds up more slowly as total biomass increases. (Wopereis *et al.*, 1996). Maximum RGR was obtained with nitrogen level N_{200} and for other treatments RGR was statistically similar except N_0. Maximum RGR at 30-60 DAT was mainly due to the higher accumulation of photosynthetic biomass started and then it tends to decrease towards growth stages due to the incretion of non-photosynthetic biomass. Moreover, the decrease in RGR is attributed for several reasons *viz*., non-photosynthetic biomass increases, the top leaves of a plant began to shade lower leaves and soil nutrients become limiting (Sridhar *et al.*, 2019) (Table 4).

Table 4. Relative growth rate of rice as influenced by varieties and nitrogen levels at different DAT

Treatments	Relative growth rate (g g^{-1} day^{-1})			
	30-60 DAT	60-75 DAT	75-90 DAT	90-105 DAT
Varieties				
V1-BRRI dhan29	0.08	0.068	0.040	0.021
V2-BRRI dhan89	0.08	0.069	0.037	0.023
S.E. (±)	0.004	0.007	0.006	0.007
CD. at 5%	NS	NS	NS	NS
Nitrogen (N) (kg/ha)				
N_0	0.07	0.056	0.027	0.012
N_{40}	0.07	0.075	0.032	0.032
N_{80}	0.08	0.065	0.031	0.026
N_{120}	0.09	0.068	0.046	0.018
N_{160}	0.08	0.066	0.031	0.022
N_{200}	0.09	0.084	0.064	0.021
S.E. (±)	0.007	0.011	0.011	0.012
CD. at 5%	0.014	0.022	0.022	NS
Interaction (V × N)				
S.E. (±)	0.009	0.016	0.015	0.016
Significance (5%)	NS	NS	NS	NS

2.7 Grain yield

Grain yield had significant effect for nitrogen level. However, interaction effect was observed insignificant for this trait. The highest grain yield was produced at nitrogen level N_{120}, N_{160} and N_{200} whereas the lowest yield production was obtained with nitrogen level N_0 (Fig.3) (Gautam *et al.*, 2005) reported that each successive increase in the level of nitrogen significantly increased the grain yield of aromatic rice. According to Bhowmick *et al.*, 2000 increase in grain weight at higher nitrogen rates might be primarily due to increase in chlorophyll content of leaves which led to higher photosynthetic rate and ultimately plenty of photosynthates available during grain development.

Based on the findings of the study the way forward could include the following directions:

1. Economic optimization – Although N160 and N200 improved growth and yield, future research should evaluate the economic return and cost–benefit ratio to determine the most profitable nitrogen rate for farmers.
2. Nitrogen use efficiency (NUE) – Further studies should assess NUE parameters to identify whether higher nitrogen rates (e.g., N200) are agronomically efficient or lead to diminishing returns and losses.
3. Environmental sustainability – Investigations into nitrogen losses (leaching, volatilization, N_2O emissions) are necessary to ensure that recommended rates do not negatively impact soil health and the environment.

4. Site-specific nutrient management – Multi locations and multi-season trials should be conducted to validate the findings under diverse agro-ecological conditions.
5. Integration with improved practices – Future research could integrate optimized nitrogen levels with precision fertilization, split application strategies, or integrated nutrient management approaches.

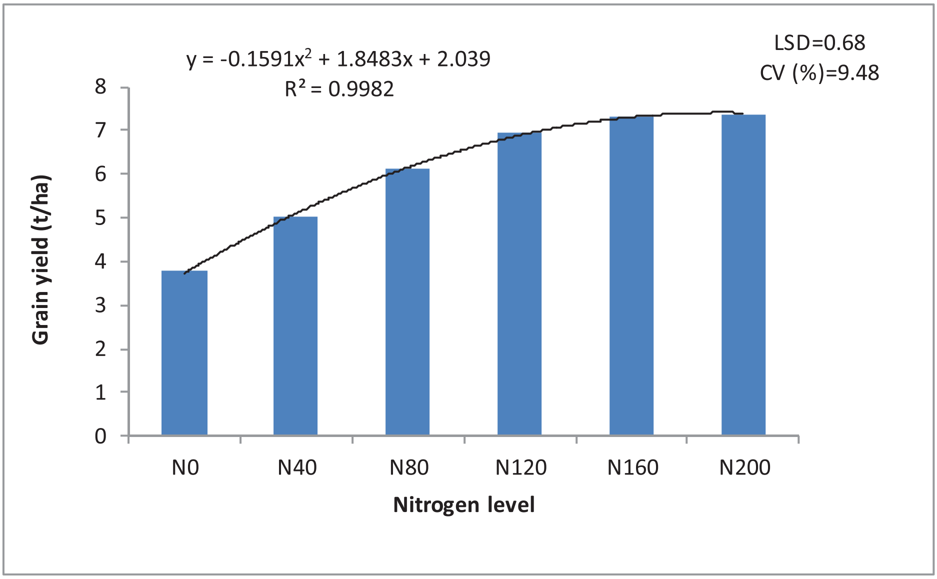

Fig. 3 Grain yield production at variable nitrogen levels.

4. Conclusions

The study demonstrated that nitrogen application significantly influenced the growth, dry matter partitioning, and yield of rice varieties. Higher nitrogen levels, particularly N160 and N200, promoted greater dry matter accumulation in leaves, culm, and panicle across all growth stages. Total dry matter production was strongly correlated with grain yield indicating its importance in yield formation. Key growth parameters including LAI, CGR and NAR were lowest at initial stage and reached to peaked between 75-90 DAT. Overall, nitrogen levels of N_{160} and N_{200} optimized physiological growth and resulted in the highest grain yield, followed by N120, highlighting the critical role of adequate nitrogen management for maximizing rice productivity. The next step of the study is to balance maximum yield, economic feasibility, and environmental sustainability to develop a refined nitrogen recommendation for rice production systems.

Conflicts of Interest

The authors declare no conflicts of interest regarding publication of this paper.

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