



RESEARCH ARTICLE

Phenological behaviour, growth, biomass partitioning and yield of black rice (*Oryza sativa* L.) under levels and sources of nitrogen

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Received: 10 October 2025; Accepted: 05 March 2026; Available online: Version 1.0: 21 May 2026

Cite this article: Subhashree N, Stuti DB, Jagadish J, Basudev B. Phenological behaviour, growth, biomass partitioning and yield of black rice (*Oryza sativa* L.) under levels and sources of nitrogen. Plant Science Today. 2026; 13(sp2): 1-14. <https://doi.org/10.14719/pst.12203>

Abstract

Proper nitrogen (N) management is crucial to unlock the productivity potential of black rice. Hence, a trial on N levels and sources was conducted in Bhubaneswar during kharif 2024 to assess the effects of treatments on crop performance. The sources comprised different proportions of urea and farmyard manure (FYM). The 3 levels of N kg ha⁻¹, viz. L₁:30, L₂:60 and L₃:90 and 5 sources of N viz. S₁: Urea (100 % N), S₂: FYM (100 % N), S₃: Urea (75 % N) + FYM (25 % N), S₄: Urea (50 % N) + FYM (50 % N), S₅: Urea (25 % N) + FYM (75 % N) were evaluated in split plot design with 3 replications. The application of 90 kg N ha⁻¹ took the maximum number of days to reach 50 % flowering and physiological maturity (PM). Biomass partitioning to leaves decreased after 50–75 days after transplanting (DAT), whereas stem biomass decreased after 100 DAT. Biomass partitioning to panicle started at 75 DAT and increased continuously till PM. Application of 60 and 90 kg N ha⁻¹ recorded significantly higher growth parameters, yield attributes and yield than 30 kg N ha⁻¹. Among the sources, the application of 75 % N as urea and 25 % N as FYM outperformed the other combinations. Application of 90 kg N ha⁻¹ as Urea N 75 % + FYM N 25 % gave the maximum grain and straw yields of 4.137 and 4.912 t ha⁻¹, respectively and was at par with 60 kg N ha⁻¹ through Urea N 75 % + FYM N 25 %. Application of 45 kg N ha⁻¹ through urea and 15 kg N through FYM saved nitrogenous fertiliser by one-third and hence, may be adopted by farmers for ensuring proper growth of black rice and maximising yield under the coastal plains of Eastern India.

Keywords: Chakhao Amubi; crop growth rate; harvest index; panicle biomass; physiological maturity

Introduction

Pigmented black rice (*Oryza sativa* L.) is receiving increased global attention in the food industry due to the health benefits associated with its anthocyanin levels in the aleurone layer that imparts violet or dark purple-black coloration (1). Anthocyanin content ranges from 79.5–473.7 mg, 100 g⁻¹ of grain, depending on cultivars, environment and method of processing (2). Black rice is gluten-free, gut-friendly and a natural cleanser with many medicinal properties compared to white rice (3). Anthocyanins decrease reactive oxygen species (ROS), which damage cells in man, animals and plants. They prevent sclerosis, improve eyesight, reduce cancer cell proliferation, lower the incidence of obesity and diabetes, and reduce inflammation (4–6). Anthocyanins play a crucial role in neuroprotection by reducing oxidative stress (7, 8). In 2023, India produced 0.11 million tons of black rice, constituting 9 % of global production, i.e., 1.2 million tons (9). Globally, organic and conventional black rice are grown in over 0.35 and 0.48 million hectares, respectively.

The yield and spread of black rice is low in India due to several bio-physical, socio-economic, technological and institutional constraints. These include cultivation of traditional varieties having taller stature and longer duration with lower yield potential, limited adoption of improved production practices by farmers, poor market linkages and price uncertainty, lack of organized market channels and exploitation by middlemen, fluctuating prices and absence of

Minimum Support Price and non-availability of high yielding seeds (10–13). These challenges need to be addressed to unlock full potential of the crop. Among these challenges, nutrient management, particularly nitrogen (N), is the key element, considering its significant role in rice physiology. Nitrogen management is important to exploit the yield potential of black rice (14). Both levels and sources of N influence yield and quality of black rice. Black rice produced the maximum grain and straw yields with the application of 150 kg N ha⁻¹ at Bapatla, India (15). The cultivar Chakhao Poreiton gave the maximum grain yield of 5.67 t ha⁻¹ at Prayagraj, India with N at the rate of 80 kg ha⁻¹ (16). The maximum values of plant height (PH), tillers per square meter and leaf area index (LAI) of lowland black rice were recorded at 35 and 70 days after transplanting (DAT) with application of N at the rate of 45 kg ha⁻¹ (17).

The efficiency of applied N fertiliser primarily depends on the form of N applied and the ecosystem in which it is used. Using organic manure offers numerous benefits because it provides a balanced nutrient supply. Use of organic manures has been found promising in arresting the decline in productivity by correcting secondary and micronutrient deficiencies and influencing the physico-chemical and biological properties of soil (18). The balanced application of nutrients from organic sources along with inorganic fertilisers is essential to fulfill crop needs, maintain soil fertility, and achieve optimal crop yields (19). Application of 50 % N (organic) +

50 % (inorganic) in black rice produced 17 and 7 % higher yield than 100 % N as inorganic and organic, respectively, during the kharif season under the mid-hills of Meghalaya (20). Several researchers concluded that application of N through organic and inorganic sources increased yield in black rice (21–24). An appropriate combination of inorganic and organic nutrient sources can increase rice productivity and quality, besides promoting healthy ecosystem (25). Application of 75 % N through inorganic fertiliser and 25 % N through cow dung manure produced the maximum values of yield attributes and yield in black rice at Mymensingh, Bangladesh (26). Against the above background, the present experiment was designed and conducted with the hypothesis that an optimal level and appropriate source of N would ensure optimal nutrient availability at different stages of growth, boost crop growth, optimise assimilate partitioning among plant parts, and achieve the maximum yield of black rice in Eastern India.

Materials and Methods

Experimental site

The experiment was conducted during kharif 2024 at the Agricultural Research Station, Binjhagiri, Chhatabar, SOADU, Bhubaneswar, India. The experimental site is located at a latitude of 20°23' N, a longitude of 85°83' E and an altitude of 25.5 meters above mean sea level.

Treatment details

The experiment aimed to assess the effects of different nitrogen levels and sources on the growth and yield of black rice. The N levels were met through varying proportions of inorganic N (urea) and farmyard manure (FYM, 0.46 % N). The 3 levels of N kg ha⁻¹, viz. L₁:30, L₂:60 and L₃:90 allocated to the main plots and 5 sources of N, viz. S₁: Urea (100 % N), S₂: FYM (100 % N), S₃: Urea (75 % N) + FYM (25 % N), S₄: Urea (50 % N) + FYM (50 % N), S₅: Urea (25 % N) + FYM (75 % N) allocated to the sub plots were evaluated in split plot design with 3 replications.

Crop management

Black rice cv. 'Chakhao Amubi' was selected as the test variety. Seeds of black rice were sown on a nursery bed on 24 June 2024. Seedlings were transplanted in the puddled main field on 22 July 2024. Well-decomposed farmyard manure (FYM) was applied to individual plots 1 day before transplanting, in accordance with the treatment specifications. 30 day old seedlings were transplanted at a spacing of 20 cm x 15 cm, with 2–3 seedlings per hill. The crop was harvested on 8 November 2024.

Sampling and data recording

Phenological studies

Days to 50 % flowering and physiological maturity (PM) were recorded based on 10 hills per plot.

Plant height

The heights of 10 tagged plants were measured from the ground to the growing tips and the mean was determined.

Number of tillers per unit area

Tiller counts were taken from 10 tagged hills; the average value was calculated and expressed as tillers per square meter.

Leaf area index

To estimate leaf area index (LAI), stage-wise specific leaf area (SLA)

was measured and expressed in cm² g⁻¹. The SLA refers to leaf area of the plant per unit leaf dry weight. Treatment-wise leaf area per hill was found out by multiplying leaf dry weight with SLA at each stage (27). Leaf area index is a measure of extent of crop canopy covering the land. It was worked out by using the following formula given by (28).

$$\text{LAI} = \frac{\text{Leaf (cm}^2\text{)}}{\text{Ground (cm}^2\text{)}} = \frac{\text{Total leaf area of hill (cm}^2\text{)}}{\text{Land area occupied by the hill (cm}^2\text{)}} \quad (\text{Eqn. 1})$$

Dry matter accumulation

Sampling hills were randomly uprooted from the destructive sampling zone of each plot. Depending on the stage, the plant components were separated into leaf (leaf lamina), stem and panicle (neck-node, rachis, grain and chaffy grains) to record plant part-wise biomass at 25, 50, 75 and 100 DAT and PM and analyse biomass partitioning behaviour at different growth and developmental stages. The above-ground parts were sun-dried for 1 to 2 days, then placed in an oven at 65 to 70 °C for 24 to 48 hr. After removal from the oven, the dry weight was determined. The average dry weight per hill was then calculated and expressed in g m⁻².

Crop growth rate

The crop growth rate (CGR) values were found by using the following formula (29).

$$\text{CGR} = \frac{W_2 - W_1}{t_2 - t_1} \quad \text{g}^{-1} \text{m}^{-2} \text{day}^{-1} \quad (\text{Eqn. 2})$$

Where, W₁ and W₂ were the total dry weight per unit area at times t₁ and t₂ respectively.

Yield and harvest Index

Harvesting was done from the net plot area. After threshing, winnowing and drying, the plot-wise grain weight was recorded at a moisture content of 12 % and expressed in t ha⁻¹. The straw yield was recorded after drying and expressed in t ha⁻¹. The HI was calculated by dividing the economic yield (grain) by the total biological yield (grain + straw), then multiplying the resulting fraction by 100.

$$\text{Harvest index (HI)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100 \quad (\text{Eqn. 3})$$

Results

Crop - weather - soil relationships

The climate of the zone is tropical, hot, humid and monsoonal in nature. All standard meteorological weeks (SMWs) were wet with the maximum precipitation of 124.3 mm on the 32nd SMW (10–16 August) and the minimum of 9.5 mm on the 44th SMW (02–08 November). The rainfall was adequate for the growth and development of the crop. The thermal regime during the crop life cycle from 24 June 2024 (25th SMW) to 08 November 2024 (44th SMW) was congenial for the growth and development of black rice. In general, the maximum and the minimum temperature decreased with the advancement of the crop life cycle (Fig. 1). The maximum temperature ranged from 37.3 °C (25 SMW, 22–28 June) to 29.8 °C (43rd SMW, 26 October – 01 November). The minimum temperature

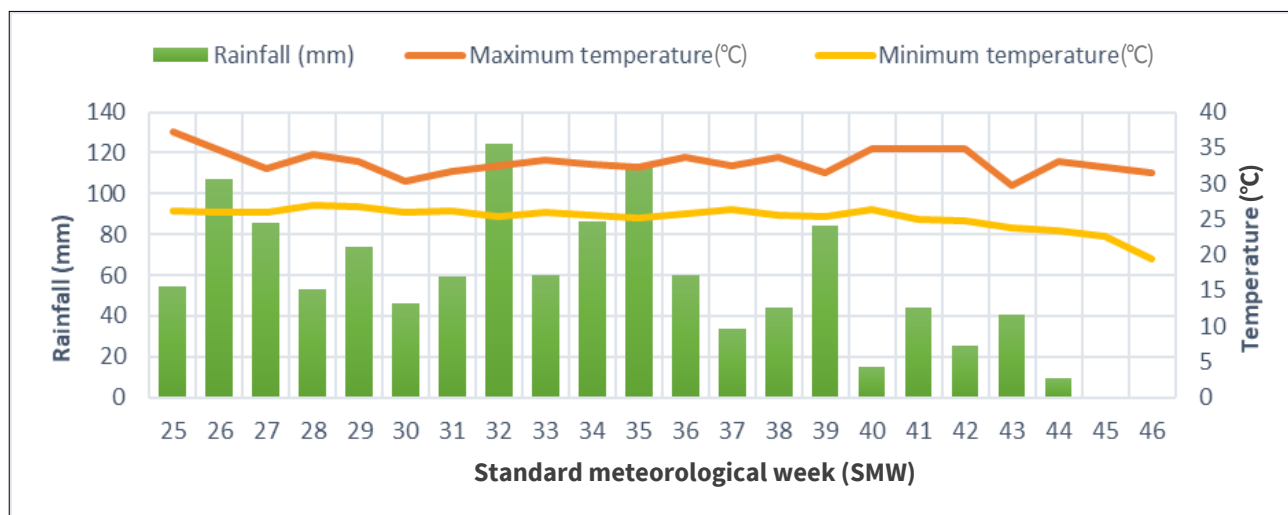


Fig. 1. Standard meteorological week-wise rainfall, maximum and minimum temperature during crop growth period.

ranged between 26.9 °C (28 SMW, 13–19 June) to 23.4 °C (44th SMW, 02–08 Nov). The soil was sandy loam in texture with pH 6.5, EC 0.09 dS m⁻¹, organic carbon 0.31 %, available N 165.3 kg ha⁻¹, available P 15.5 kg ha⁻¹ and available K 230.5 kg ha⁻¹. There were no edaphic limitations to hinder crop growth.

Crop phenology

Among N levels, application of 90 kg N ha⁻¹ took the maximum days to 50 % flowering (107 days) and PM (142 days), followed by 60 kg N ha⁻¹ and 30 kg N ha⁻¹ (Fig. 2). The crop took the maximum days for attainment of 50 % flowering (107 days) and PM (142 days) with application of 100 % N through urea, whereas, the crop attained these 2 stages at the earliest with application of N as Urea (25 % N) + FYM (75 % N).

Growth parameters

Plant height

Nitrogen levels influenced PH at 50 and 75 DAT and PM (Table 1). The application of 90 and 60 kg N ha⁻¹ resulted in significantly greater PH than the lowest level (30 kg N ha⁻¹). Nitrogen sources significantly influenced PH at 75 DAT and PM. Supply of 75 % N through urea + 25 % N through FYM produced the tallest plant at all the stages,

being at par with urea (100 % N), urea (50 % N) + FYM (50 % N) and urea (25 % N) + FYM (75 % N). Application of 100 % N through FYM resulted in the lowest PH.

Number of tillers per unit area

The tillers per square meter increased from 25 to 50 DAT, then declined thereafter until PM (Table 2). The two higher levels of (90 and 60 kg ha⁻¹) produced higher tillers per square meter than the lowest level. Application of 60 and 90 kg N ha⁻¹ increased the tillers per square meter by 11 and 19 % at 25 DAT, 6 and 7 % at 50 DAT, 6 and 12 % at 75 DAT and 5 and 12 % at PM over 30 kg N ha⁻¹, respectively. Among sources, application of urea (75 % N) + FYM (25 % N) recorded the maximum tillers per square meter at all the stages, being at par with S₄ and S₅ at 50 DAT, S₄ at 75 DAT and S₄ at PM. The application of 100 % N through FYM resulted in the fewest tillers per square meter across all stages.

Leaf area index

The LAI values increased progressively from 25 DAT to 75 DAT with advancing stages and then declined thereafter. Across all levels, applying 90 kg N ha⁻¹ resulted in the maximum LAI at all stages. The application of 60 kg N ha⁻¹ resulted in statistically similar LAI at 25 and 100 DAT (Table 3). Among the different sources of N, the application

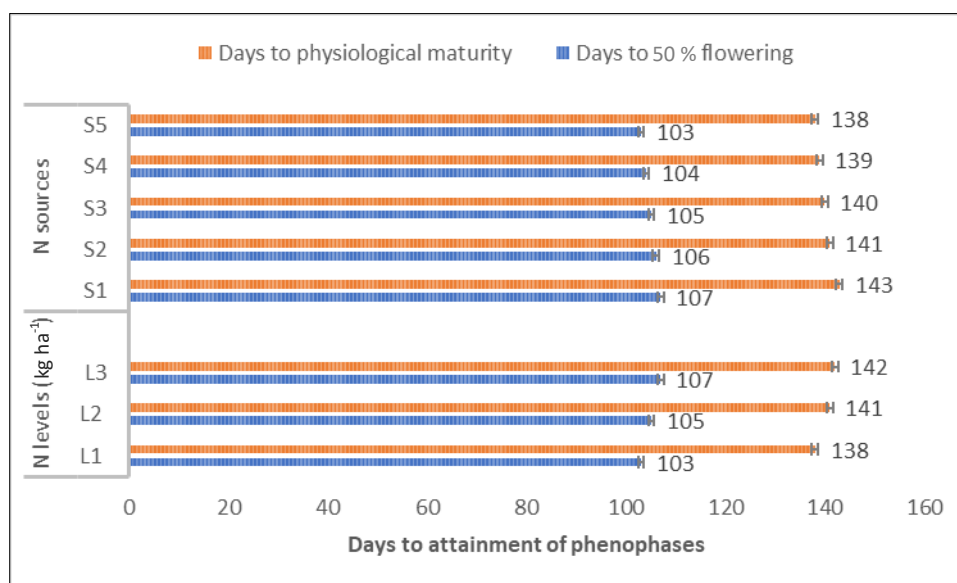


Fig. 2. Effect of levels and sources of nitrogen on days to attainment of phenophases.

L1: 30 kg N ha⁻¹; L2: 60 kg N ha⁻¹; L3: 90 kg N ha⁻¹; S1: Urea (100 % N); S2: FYM (100 % N); S3: Urea (75 % N) + FYM (25 % N); S4: Urea (50 % N) + FYM (50 % N); S5: Urea (25 % N) + FYM (75 % N).

Table 1. Effect of levels and sources of nitrogen on the plant height (cm) of black rice

Treatment	25 DAT	50 DAT	75 DAT	PM
Nitrogen levels (kg ha⁻¹)				
L ₁ - 30	49.8	78.0	100.2	121.9
L ₂ - 60	50.0	83.1	105.5	125.4
L ₃ - 90	51.2	88.5	110.8	131.3
SEm±	0.7	1.43	1.85	1.70
CD ($p = 0.05$)	NS	5.6	7.2	6.7
Sources of nitrogen				
S ₁ - Urea (100 % N)	48.6	82.6	105.3	125.7
S ₂ - FYM (100 % N)	49.7	81.2	100.4	120.9
S ₃ - Urea (75 % N) + FYM (25 % N)	52.6	84.5	109.7	131.7
S ₄ - Urea (50 % N) + FYM (50 % N)	51.0	84.4	106.4	126.6
S ₅ - Urea (25 % N) + FYM (75 % N)	49.6	83.3	105.7	126.2
SEm±	1.6	0.91	1.87	2.22
CD ($p = 0.05$)	NS	NS	5.5	6.3

DAT: Days after transplanting; FYM: Farmyard manure; SEm±: Standard error of mean; CD: Critical difference.

Table 2. Effect of levels and sources of nitrogen on the tillers m⁻²

Treatment	25 DAT	50 DAT	75 DAT	100 DAT
Nitrogen levels (kg ha⁻¹)				
L ₁ - 30	169	322	302	237
L ₂ - 60	188	342	320	250
L ₃ - 90	201	344	337	266
SEm±	5	3	6	5
CD ($p = 0.05$)	20	13	22	21
Sources of nitrogen				
S ₁ - Urea (100 % N)	185	334	312	256
S ₂ - FYM (100 % N)	176	323	306	224
S ₃ - Urea (75 % N) + FYM (25 % N)	208	347	340	273
S ₄ - Urea (50 % N) + FYM (50 % N)	175	340	323	262
S ₅ - Urea (25 % N) + FYM (75 % N)	186	335	315	239
SEm±	6	7	7	9
CD ($p = 0.05$)	18	22	20	26

DAT: Days after transplanting; FYM: Farmyard manure; SEm±: Standard error of mean; CD: Critical difference.

Table 3. Effect of levels and sources of nitrogen on leaf area index of black rice

Treatment	25 DAT	50 DAT	75 DAT	100 DAT
Nitrogen levels (kg ha⁻¹)				
L ₁ - 30	1.35	1.46	3.54	1.22
L ₂ - 60	1.45	1.97	4.08	1.48
L ₃ - 90	1.65	2.33	4.25	1.67
SEm±	0.04	0.07	0.16	0.07
CD ($p = 0.05$)	0.17	0.28	NS	0.28
Sources of nitrogen				
S ₁ - Urea (100 % N)	1.42	1.87	3.72	1.38
S ₂ - FYM (100 % N)	1.35	1.39	3.62	1.41
S ₃ - Urea (75 % N) + FYM (25 % N)	1.87	2.26	4.43	1.61
S ₄ - Urea (50 % N) + FYM (50 % N)	1.49	2.19	4.24	1.47
S ₅ - Urea (25 % N) + FYM (75 % N)	1.29	1.90	3.76	1.41
SEm±	0.08	0.17	0.26	0.06
CD ($p = 0.05$)	0.23	0.49	NS	NS

DAT: Days after transplanting; FYM: Farmyard manure; SEm±: Standard error of mean; CD: Critical difference.

of 75 % N as urea + 25 % N as FYM yielded the maximum LAI. Application of N through urea alone, 50 % N through urea + 50 % N through FYM and 25 % N through urea + 75 % N through FYM recorded statistically similar LAI at 50 DAT only.

Biomass partitioning

Twenty five days after transplanting

The leaf biomass of 62.54 g per square meter (52 %) and stem biomass of 57.61 g m⁻² (48 %) led to crop biomass of 120.15 g m⁻² (Table 4). Among N levels, application of 90 kg N ha⁻¹ recorded the maximum crop biomass of 130.9 g m⁻² at 25 DAT, comprising leaf biomass of 68.7 g m⁻² (52 %) and stem biomass of 62.2 g m⁻² (48 %).

Application of 60 kg N ha⁻¹ (117.9 g m⁻²) recorded statistically similar crop biomass at 25 DAT, whereas application of 30 kg N ha⁻¹ recorded significantly less crop biomass. Among the N sources, application of 75 % N through urea + 25 % N through FYM recorded the maximum crop biomass of 150.7 g m⁻², comprising leaf and stem biomass of 77.1 and 73.6 g m⁻² respectively. Other N levels recorded significantly less biomass. The interaction effects of N levels and sources were significant on crop biomass at 25 DAT (Fig. 3). Application of 60 kg N ha⁻¹ comprising 100 % N through urea (L₂S₁) recorded the maximum crop biomass of 188.7 g m⁻² and L₃S₃ and L₃S₂ recorded statistically similar crop values.

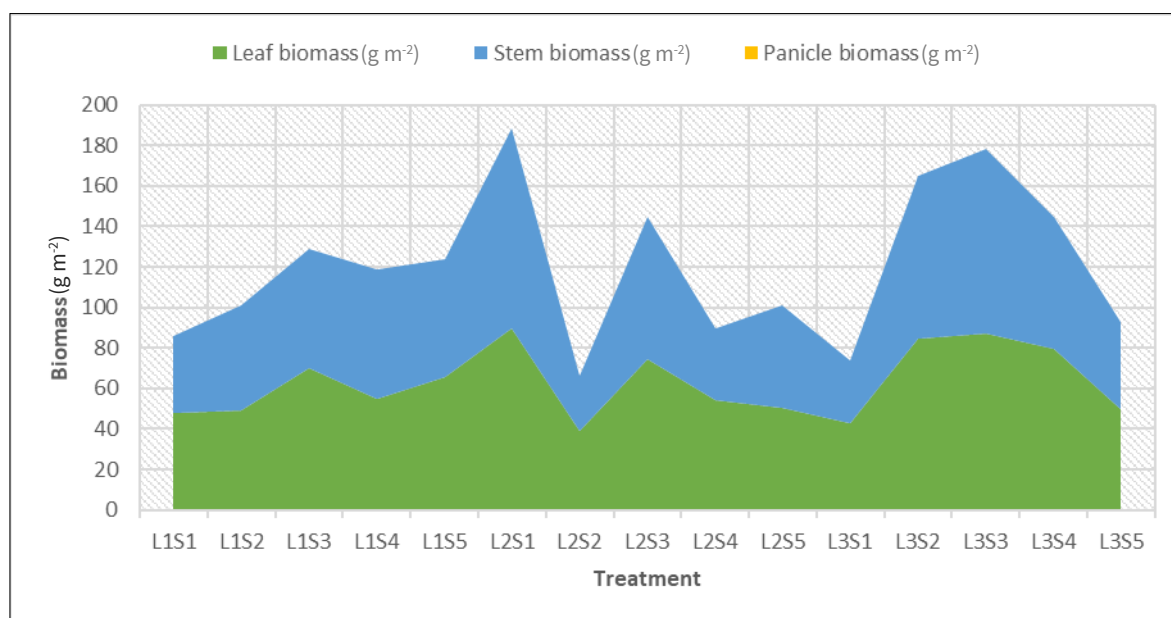
Table 4. Effect of levels and sources of nitrogen on biomass production (g m^{-2}) at 25 DAT of black rice

Treatment	Leaf biomass	Stem biomass	Crop
Nitrogen levels (kg ha^{-1})			
L ₁ - 30	57.48	54.16	111.7
L ₂ - 60	61.47	56.45	117.9
L ₃ - 90	68.66	62.23	130.9
SEm±	1.65	2.97	3.70
CD ($p = 0.05$)	6.5	NS	14.5
Sources of nitrogen			
S ₁ - Urea (100 % N)	60.0	56.1	115.1
S ₂ - FYM (100 % N)	57.6	53.2	110.8
S ₃ - Urea (75 % N) + FYM (25 % N)	77.1	73.6	150.7
S ₄ - Urea (50 % N) + FYM (50 % N)	62.7	54.8	117.5
S ₅ - Urea (25 % N) + FYM (75 % N)	55.3	50.4	105.7
SEm±	3.0	3.06	4.49
CD ($p = 0.05$)	8.8	8.9	13.1

DAT: Days after transplanting; FYM: Farmyard manure; SEm±: Standard error of mean; CD: Critical difference.

Fifty days after transplanting

The leaf biomass of 91.35 g m^{-2} (45 %) and stem biomass of 109.45 g m^{-2} (55 %) led to crop biomass of 200.80 g m^{-2} (Table 5). At 50 DAT, application of 90 kg N ha^{-1} recorded the maximum crop biomass of 257.1 g m^{-2} , comprising leaf biomass of 104.2 g m^{-2} (40 %) and stem biomass of 152.9 g m^{-2} (60 %) and proved significantly superior to other lower levels of N. The proportion of leaf biomass decreased from 52 % at 25 DAT to 45 % at 50 DAT and the stem biomass increased from 48 % at 25 DAT to 55 % at 50 DAT (Table 5). Among the different sources of N, 75 % N through urea + 25 % N through FYM recorded the maximum biomass of 222.2 g m^{-2} , comprising 101.6 g m^{-2} of leaf biomass and 120.5 g m^{-2} of stem biomass. The N sources viz. S₄, S₅ and S₁ were at par with S₃ for leaf, stem and crop biomass. The interaction effects of N levels and sources were significant on crop biomass at 50 DAT (Fig. 4). Application of 90 kg N ha^{-1} comprising 25 % N through urea + 75 % N through FYM (L₃S₅) recorded the maximum crop biomass of 294.05 g m^{-2} and L₃S₁, L₃S₃ and L₃S₄ recorded statistically similar crop biomass values.

**Fig. 3.** Effect of levels and sources of nitrogen on biomass production (g m^{-2}) at 25 days after transplanting of black rice.

L₁: 30 kg N ha^{-1} ; L₂: 60 kg N ha^{-1} ; L₃: 90 kg N ha^{-1} ; S₁: Urea (100 % N); S₂: FYM (100 % N); S₃: Urea (75 % N) + FYM (25 % N); S₄: Urea (50 % N) + FYM (50 % N); S₅: Urea (25 % N) + FYM (75 % N).

Table 5. Effect of levels and sources of nitrogen on biomass production (g m^{-2}) at 50 DAT of black rice

Treatment	Leaf biomass	Stem biomass	Crop
Nitrogen levels (kg ha^{-1})			
L ₁ - 30	76.6	73.3	149.9
L ₂ - 60	93.3	102.1	195.4
L ₃ - 90	104.2	152.9	257.1
SEm±	2.20	5.70	6.64
CD ($p = 0.05$)	8.60	22.3	26.1
Sources of nitrogen			
S ₁ - Urea (100 % N)	91.1	107.3	198.4
S ₂ - FYM (100 % N)	72.0	92.2	164.2
S ₃ - Urea (75 % N) + FYM (25 % N)	101.6	120.5	222.2
S ₄ - Urea (50 % N) + FYM (50 % N)	98.9	113.9	212.9
S ₅ - Urea (25 % N) + FYM (75 % N)	93.0	113.3	206.3
SEm±	5.9	6.86	8.80
CD ($p = 0.05$)	17.1	20.0	25.7

DAT: Days after transplanting; FYM: Farmyard manure; SEm±: Standard error of mean; CD: Critical difference.

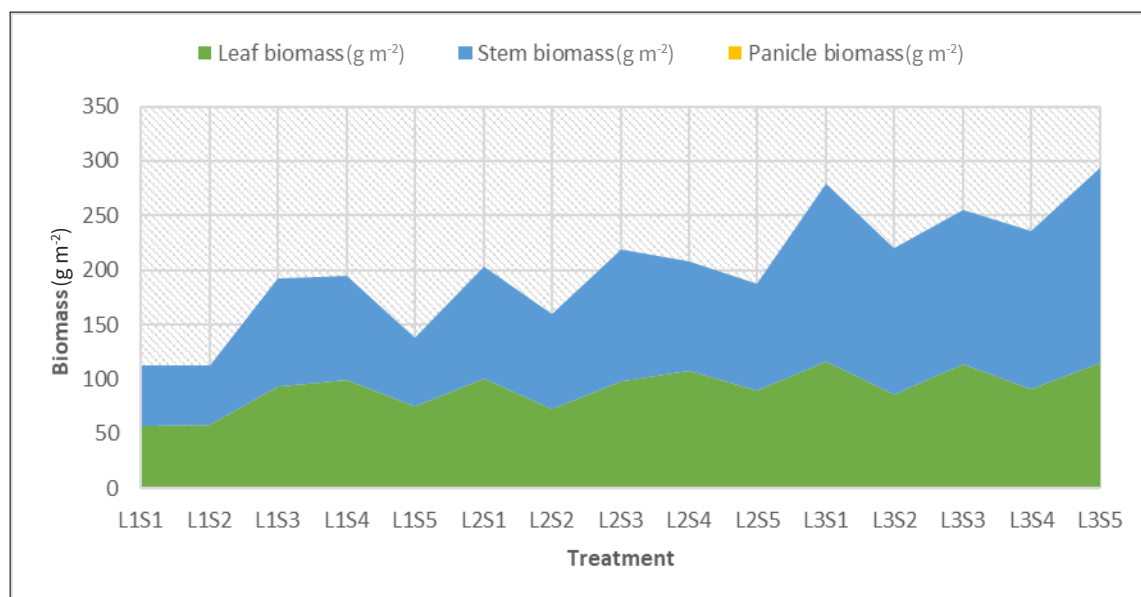


Fig. 4. Effect of levels and sources of nitrogen on biomass production (g m^{-2}) at 50 days after transplanting of black rice.

L1: 30 kg N ha^{-1} ; L2: 60 kg N ha^{-1} ; L3: 90 kg N ha^{-1} ; S1: Urea (100 % N); S2: FYM (100 % N); S3: Urea (75 % N) + FYM (25 % N); S4: Urea (50 % N) + FYM (50 % N); S5: Urea (25 % N) + FYM (75 % N).

Seventy-five days after transplanting

The leaf biomass of 86.02 g m^{-2} (26 %), stem biomass of 155.46 g m^{-2} (46 %) and panicle biomass of 92.11 g m^{-2} (28 %) led to crop biomass of 333.59 g m^{-2} . At 75 DAT, leaf, stem and panicle contributed to total crop biomass. The N levels influenced stem, panicle and crop biomass significantly at 75 DAT (Table 6). Among N levels, application of 90 kg N ha^{-1} produced the maximum crop biomass of 370 g m^{-2} , comprising leaf biomass of 91.1 g m^{-2} (25 %), stem biomass of 165.7 g m^{-2} (45 %) and panicle biomass of 113.2 g m^{-2} (30 %) (Table 6). Among the different sources of N, application of 50 % N through urea + 50 % N through FYM produced the maximum crop biomass of 368.1 g m^{-2} , which was at par with S_3 (368.0 g m^{-2}). Under S_4 , leaf, stem and panicle constituted 25, 48 and 27 % of total crop biomass, whereas under S_3 the leaf, stem and panicle contributed 26, 48 and 26 % of total crop biomass. The interaction effects of N levels and sources were significant on crop biomass at 75 DAT (Fig. 5). Application of 60 kg N ha^{-1} comprising 50 % N through urea + 50 % N through FYM (L_2S_4) recorded the maximum crop biomass of 412.68 g m^{-2}

m^{-2} and L_3S_3 , L_2S_3 and L_3S_4 recorded statistically similar crop biomass values.

Hundred days after transplanting

The leaf biomass of 83.86 g m^{-2} (13 %), stem biomass of 280.31 g m^{-2} (42 %) and panicle biomass of 298.78 g m^{-2} (45 %) led to crop biomass of 662.95 g m^{-2} . Among N levels, application of 90 kg N ha^{-1} produced the maximum crop biomass of 723.9 g m^{-2} , comprising 97.2 g m^{-2} (13 %) of leaf biomass, 290.4 g m^{-2} (40 %) of stem biomass and 336.3 g m^{-2} (47 %) of panicle biomass (Table 7). Different sources of N influenced the stem and panicle biomass significantly at 100 DAT. Application of 75 % N through urea + 25 % N through FYM produced the maximum crop biomass of 699.8 g m^{-2} , comprising 93.4 g m^{-2} of leaf biomass, 293.3 g m^{-2} of stem biomass and 313.1 g m^{-2} of panicle biomass. Application of 50 % N through urea + 50 % N through FYM produced statistically similar crop biomass of 684.5 g m^{-2} , comprising 84.7 g m^{-2} of leaf biomass, 289.5 g m^{-2} of stem biomass and 310.3 g m^{-2} of panicle biomass. The interaction effects of N levels and sources were significant on crop biomass at 100 DAT (Fig. 6). Application of 90 kg N ha^{-1} comprising

Table 6. Effect of levels and sources of nitrogen on biomass production (g m^{-2}) at 75 DAT of black rice

Treatment	Leaf biomass	Stem biomass	Panicle biomass	Crop
Nitrogen levels (kg ha^{-1})				
L ₁ - 30	78.8	136.6	69.5	284.8
L ₂ - 60	88.2	164.1	93.7	345.9
L ₃ - 90	91.1	165.7	113.2	370.0
SEm±	2.86	5.06	5.13	7.01
CD($p = 0.05$)	NS	19.9	20.1	27.5
Sources of nitrogen				
S ₁ - Urea (100 % N)	81.9	133.1	91.4	306.4
S ₂ - FYM (100 % N)	80.2	130.0	84.2	294.5
S ₃ - Urea (75 % N) + FYM (25 % N)	94.3	178.1	95.6	368.0
S ₄ - Urea (50 % N) + FYM (50 % N)	91.0	176.5	100.5	368.1
S ₅ - Urea (25 % N) + FYM (75 % N)	82.7	159.5	88.8	331.1
SEm±	4.46	5.10	4.19	8.02
CD ($p = 0.05$)	NS	14.9	NS	23.4

DAT: Days after transplanting; FYM: Farmyard manure; SEm±: Standard error of mean; CD: Critical difference.

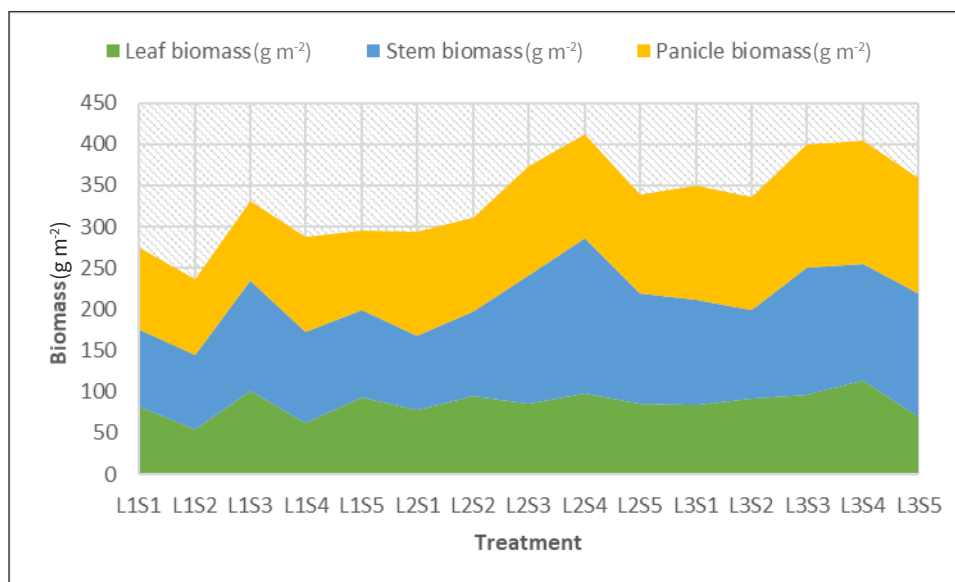


Fig. 5. Effect of levels and sources of nitrogen on biomass production (g m^{-2}) at 75 days after transplanting of black rice.

L1: 30 kg N ha^{-1} ; L2: 60 kg N ha^{-1} ; L3: 90 kg N ha^{-1} ; S1: Urea (100 % N); S2: FYM (100 % N); S3: Urea (75 % N) + FYM (25 % N); S4: Urea (50 % N) + FYM (50 % N); S5: Urea (25 % N) + FYM (75 % N).

Table 7. Effect of levels and sources of nitrogen on biomass production (g m^{-2}) at 100 DAT of black rice

Treatment	Leaf biomass	Stem biomass	Panicle biomass	Crop
Nitrogen levels (kg ha^{-1})				
L1 - 30	69.3	268.5	254.3	592.1
L2 - 60	85.1	282.1	305.7	672.9
L3- 90	97.2	290.4	336.3	723.9
SEm $\pm$	4.36	1.95	7.87	6.35
CD ($p = 0.05$)	17.1	7.7	30.9	24.9
Sources of nitrogen				
S1- Urea (100 % N)	79.4	271.3	280.9	631.5
S2- FYM (100 % N)	80.9	268.2	290.3	639.4
S3- Urea (75 % N) + FYM (25 % N)	93.4	293.3	313.1	699.8
S4- Urea (50 % N) + FYM (50 % N)	84.7	289.5	310.3	684.5
S5- Urea (25 % N) + FYM (75 % N)	81.0	279.2	299.2	659.4
SEm $\pm$	3.91	5.67	6.75	9.92
CD ($p = 0.05$)	NS	16.6	19.7	29.0

DAT: Days after transplanting; FYM: Farm yard manure; SEm $\pm$: Standard error of mean; CD: Critical difference.

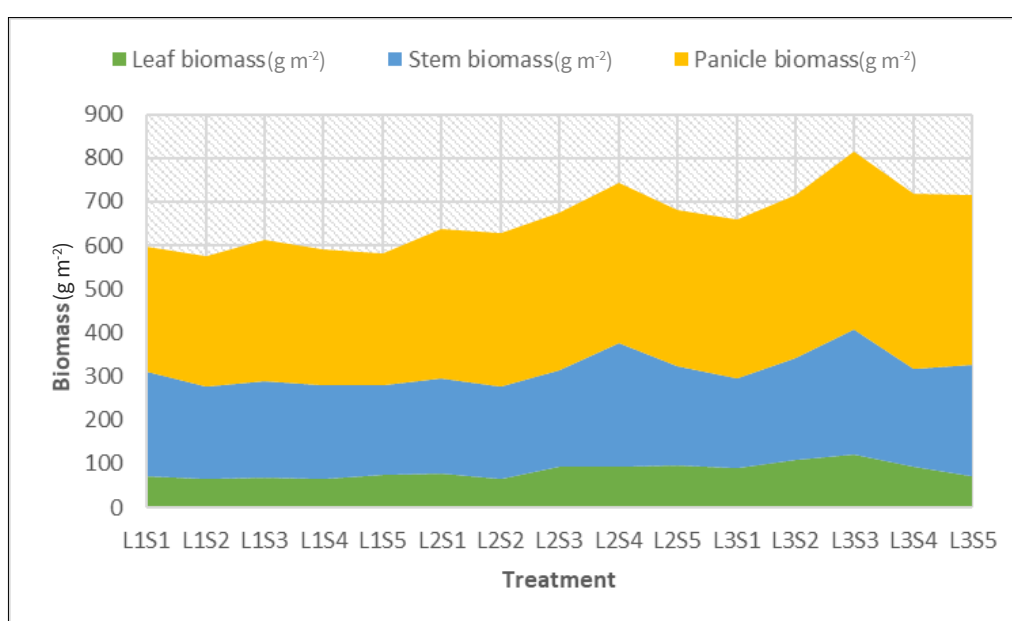


Fig. 6. Effect of levels and sources of nitrogen on biomass production (g m^{-2}) at 100 days after transplanting of black rice.

L1: 30 kg N ha^{-1} ; L2: 60 kg N ha^{-1} ; L3: 90 kg N ha^{-1} ; S1: Urea (100 % N); S2: FYM (100 % N); S3: Urea (75 % N) + FYM (25 % N); S4: Urea (50 % N) + FYM (50 % N); S5: Urea (25 % N) + FYM (75 % N).

75 % N through urea + 25 % N through FYM (L₃S₃) recorded the maximum crop biomass of 813.50 g m⁻² and proved significantly superior to other treatments.

Physiological maturity

The leaf biomass of 79.38 g m⁻² (10 %), stem biomass of 258.42 g m⁻² (35 %) and panicle biomass of 406.94 g m⁻² (55 %) led to crop biomass of 742.49 g m⁻². Different levels of N exerted significant influence on leaf, stem and crop biomass significantly at PM. Application of 90 kg N ha⁻¹ produced the maximum crop biomass of 817.5 g m⁻², comprising leaf biomass of 88.4 g m⁻², stem biomass of 271.9 g m⁻² and panicle biomass of 457.2 g m⁻² (Table 8). At PM, application of 75 % N through urea + 25 % N through FYM produced the leaf biomass of 85.8 g m⁻² (9 %), stem biomass of 267.8 g m⁻² (16 %) and panicle biomass of 430.2 g m⁻² (75 %), leading to crop biomass of 783.8 g m⁻². Application of 50 % N through urea + 50 % N through FYM produced statistically similar crop biomass of 766.7 g m⁻², comprising leaf, stem and panicle biomass of 79.9, 264.4 and 422.3 g m⁻², respectively. The interaction effects of N levels and sources were significant on crop biomass at 100 DAT (Fig. 7). Application of 90 kg N ha⁻¹ comprising 75 % N through urea + 25 % N through FYM (L₃S₃) recorded the maximum crop biomass of 911.12 g m⁻² and proved significantly superior to other treatments.

Biomass accrual dynamics

Leaf, stem and panicle biomass as influenced by treatments at different stages have been depicted in Fig. 8, 9 & 10. In most of the treatments, leaf biomass was the maximum at 50 DAT under the majority of treatments (Fig. 8). In a few cases, the maximum leaf biomass was recorded at the subsequent stages. However, the leaf biomass declined between 100 DAT to PM. Stem biomass exhibited an increasing trend till 100 DAT and declined thereafter (Fig. 9). Panicle biomass was recorded for the first time at 75 DAT, and the biomass increased continuously till PM (Fig. 10).

Biomass partitioning to the panicle at panicle maturity

Panicle (grain + chaffy grain + rachis) constituted 52–58 % of crop biomass at PM (Fig. 11). All treatments involving 60 and 90 kg N ha⁻¹ excelled over treatments involving 30 kg N ha⁻¹ for the share of panicle biomass as a percentage of total crop biomass.

Crop growth rate

The CGR values of black rice were recorded during 25–50 DAT, 50–75 DAT, 75–100 DAT and 100 DAT-PM. The CGR values increased progressively from the minimum at 25–50 DAT to the maximum at 75–100 DAT, then declined thereafter from 100 DAT-PM (Table 9). Among various levels of N, application of 90 kg N ha⁻¹ recorded the

Table 8. Effect of levels and sources of nitrogen on biomass production (g m⁻²) at physiological maturity of black rice

Treatment	Leaf biomass	Stem biomass	Panicle biomass	Crop
Nitrogen levels (kg ha⁻¹)				
L ₁ - 30	69.6	245.6	348.0	663.1
L ₂ - 60	80.2	257.8	415.6	753.6
L ₃ - 90	88.4	271.9	457.2	817.5
SEm±	2.93	1.75	7.66	7.11
CD (p = 0.05)	11.5	6.9	30.1	27.9
Sources of nitrogen				
S ₁ - Urea (100 % N)	76.4	248.1	382.9	707.3
S ₂ - FYM (100 % N)	77.4	245.4	393.4	716.2
S ₃ - Urea (75 % N) + FYM (25 % N)	85.8	267.8	430.2	783.8
S ₄ - Urea (50 % N) + FYM (50 % N)	79.9	264.4	422.3	766.7
S ₅ - Urea (25 % N) + FYM (75 % N)	77.4	266.4	405.9	749.5
SEm±	2.63	5.08	7.81	11.12
CD (p = 0.05)	NS	14.8	22.8	32.4

DAT: Days after transplanting; FYM: Farmyard manure; SEm± :Standard error of mean; CD: Critical difference.

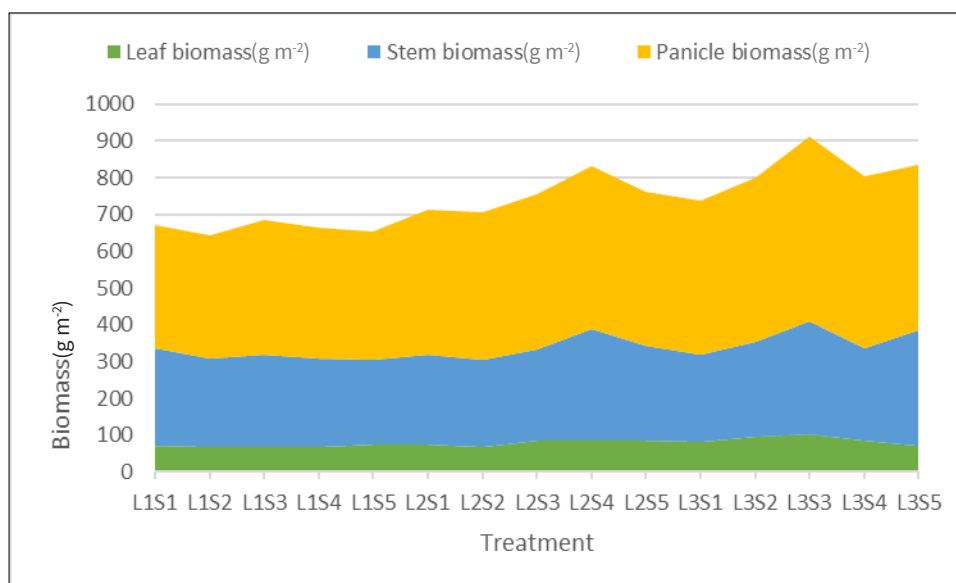


Fig. 7. Effect of levels and sources of nitrogen on biomass accumulation by plant components (g m⁻²) at physiological maturity of black rice.

L₁: 30 kg N ha⁻¹; L₂: 60 kg N ha⁻¹; L₃: 90 kg N ha⁻¹; S₁: Urea (100 % N); S₂: FYM (100 % N); S₃: Urea (75 % N) + FYM (25 % N); S₄: Urea (50 % N) + FYM (50 % N); S₅: Urea (25 % N) + FYM (75 % N).

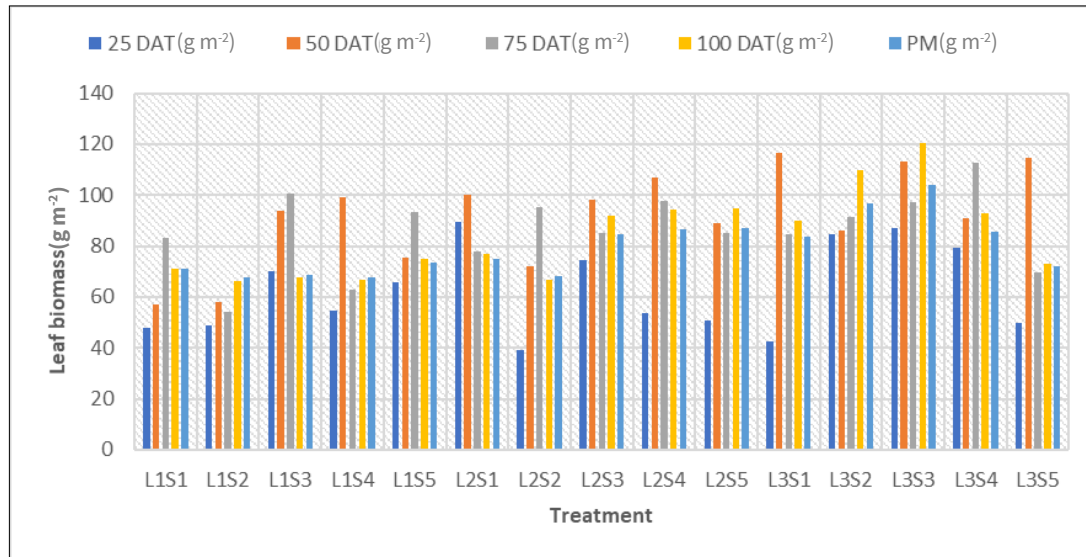


Fig. 8. Effect of levels and sources of nitrogen on leaf biomass at different stages of growth.

L1: 30 kg N ha⁻¹; L2: 60 kg N ha⁻¹; L3: 90 kg N ha⁻¹; S1: Urea (100 % N); S2: FYM (100 % N); S3: Urea (75 % N) + FYM (25 % N); S4: Urea (50 % N) + FYM (50 % N); S5: Urea (25 % N) + FYM (75 % N); DAT: Days after transplanting.

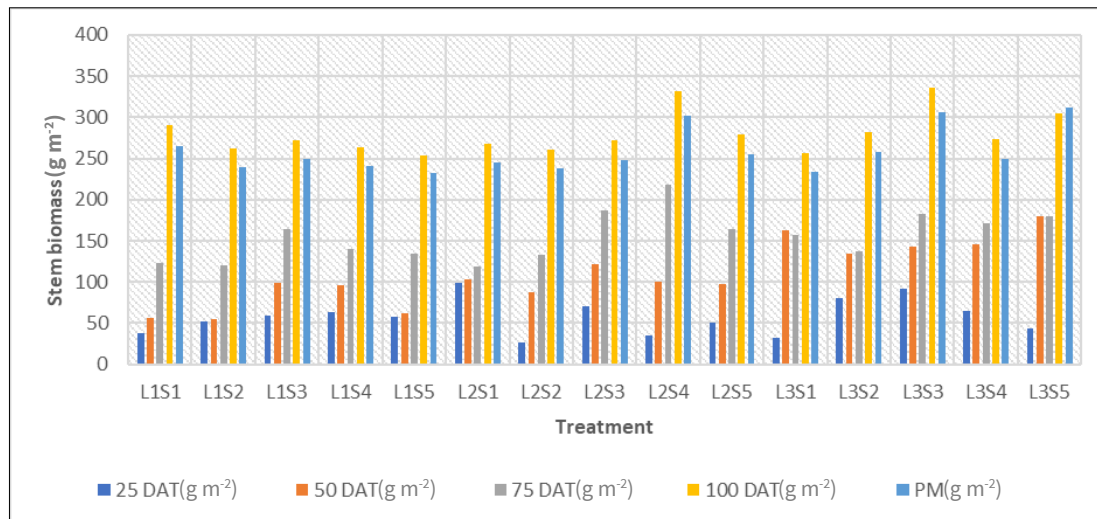


Fig. 9. Effect of levels and sources of nitrogen on stem biomass at different stages of growth.

L1: 30 kg N ha⁻¹; L2: 60 kg N ha⁻¹; L3: 90 kg N ha⁻¹; S1: Urea (100 % N); S2: FYM (100 % N); S3: Urea (75 % N) + FYM (25 % N); S4: Urea (50 % N) + FYM (50 % N); S5: Urea (25 % N) + FYM (75 % N); DAT: Days after transplanting.

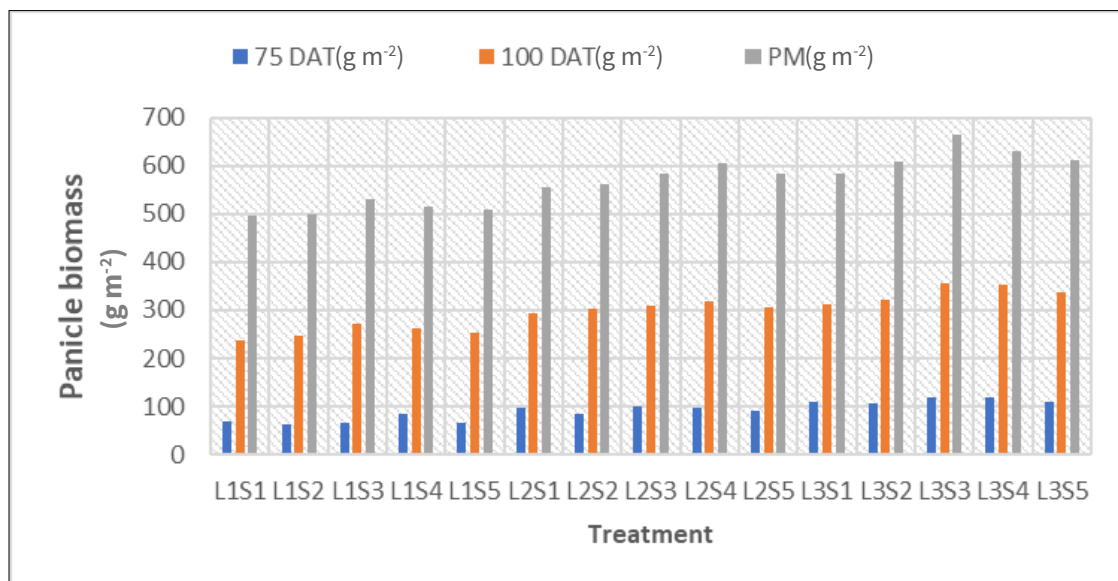


Fig. 10. Effect of levels and sources of nitrogen on panicle biomass at different stages.

L1: 30 kg N ha⁻¹; L2: 60 kg N ha⁻¹; L3: 90 kg N ha⁻¹; S1: Urea (100 % N); S2: FYM (100 % N); S3: Urea (75 % N) + FYM (25 % N); S4: Urea (50 % N) + FYM (50 % N); S5: Urea (25 % N) + FYM (75 % N); DAT: Days after transplanting.

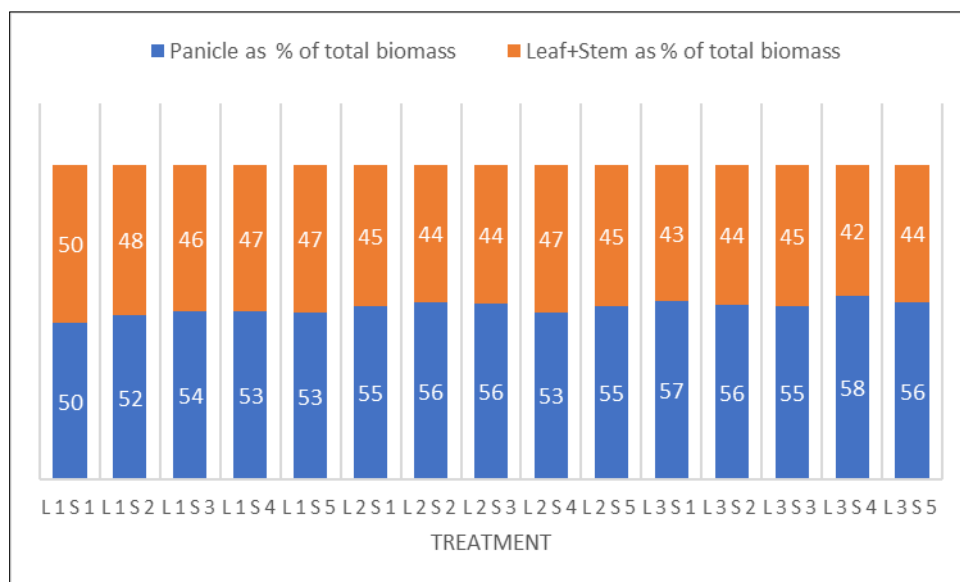


Fig. 11. Biomass partitioning (%) to panicle and leaf + stem at physiological maturity under levels and sources of nitrogen.

L1: 30 kg N ha⁻¹; L2: 60 kg N ha⁻¹; L3: 90 kg N ha⁻¹; S1: Urea (100 % N); S2: FYM (100 % N); S3: Urea (75 % N) + FYM (25 % N); S4: Urea (50 % N) + FYM (50 % N); S5: Urea (25 % N) + FYM (75 % N).

Table 9. Effect of levels and sources of nitrogen on the crop growth rate of black rice

Treatment	Crop growth rate (g m ⁻² day ⁻¹)			
	25–50 DAT	50–75 DAT	75–100 DAT	100 DAT-PM
Nitrogen levels (kg ha⁻¹)				
L ₁ - 30	1.53	5.40	10.97	7.10
L ₂ - 60	3.10	6.02	11.68	8.07
L ₃ - 90	5.05	4.51	12.64	8.69
SEm±	0.31	0.53	1.00	0.08
CD (<i>p</i> = 0.05)	1.2	NS	3.9	0.3
Sources of nitrogen				
S ₁ - Urea (100 % N)	3.29	4.32	11.61	7.58
S ₂ - FYM (100 % N)	2.14	5.21	12.32	7.67
S ₃ - Urea (75 % N) + FYM (25 % N)	2.86	5.83	11.85	8.40
S ₄ - Urea (50 % N) + FYM (50 % N)	3.81	6.21	11.30	8.21
S ₅ - Urea (25 % N) + FYM (75 % N)	4.03	4.99	11.73	7.91
SEm±	0.40	0.44	0.49	0.12
CD (<i>p</i> = 0.05)	1.2	1.3	NS	0.3

DAT: Days after transplanting; FYM: Farm yard manure; SEm± :Standard error of mean; CD: Critical difference.

maximum CGR values of 5.05, 12.64 and 8.69 g⁻¹m²day⁻¹ during 25–50 DAT, 75–100 DAT and 100 DAT-PM, respectively (Table 10). The decline in CGR during 100 DAT-PM was due to leaf senescence and a gradual reduction in leaf area and photosynthetic rate. Among various sources, application of 25 % N through urea + 75 % N through FYM recorded the maximum CGR of 4.03 g⁻¹m²day⁻¹, being at par with S₁, S₃ and S₄. During 50–75 DAT, 75 % N through urea + 25 % N through FYM recorded the maximum CGR of 5.83 g⁻¹m²day⁻¹, being at par with S₂, S₄ and S₅.

Yield attributes

Application of 90 kg N ha⁻¹ produced the longest panicle (23.1 cm) with maximum, panicle per square meter (292) and filled grains per panicle (79.1) and the heaviest grain (25.78 g 1000 grains⁻¹), being at par with 60 kg N ha⁻¹ for panicle length (23 cm), panicle per square meter (291), filled grains per panicle (77.2) and test weight (25.29 g 1000 grains⁻¹). Application of 30 kg N ha⁻¹ recorded significantly lower values of yield attributes than 90 and 60 kg N ha⁻¹ (Table 4.11). Among various sources, 75 % N through urea + 25 % N through FYM produced the longest panicle (23.1 cm), panicle per square meter (295), the maximum filled grains panicle⁻¹ (78.9) and the heaviest grain (26.12 g 1000 grains⁻¹). For filled grains per panicle, S₁ and S₂

recorded statistically similar filled grain per panicle as S₅.

Yield and harvest index

Both N levels and sources significantly influenced the grain and straw yields of black rice. Application of 90 kg N ha⁻¹ produced the maximum grain yield of 3.292 t ha⁻¹, being at par with 60 kg N ha⁻¹ (3.081 t ha⁻¹). Application of 60 and 90 kg N ha⁻¹ increased grain yield by 18 and 26 %, respectively, over 30 kg N ha⁻¹ (Table 11). Among the sources, application of 75 % N through urea + 25 % N through FYM recorded the maximum grain yield of 3.539 t ha⁻¹ and proved significantly superior to other N sources. Application of 75 % N through urea + 25 % N through FYM increased grain yield by 23, 35, 16 and 23 % over urea alone, FYM alone, 50 % N through urea + 50 % N through FYM and 25 % N through urea + 75 % N through FYM, respectively. The interaction effect of N levels and sources on grain yield in black rice was significant. Application of 90 kg N ha⁻¹ utilising 75 % N through urea + 25 % N through FYM produced the maximum grain yield of 4.137 t ha⁻¹, being at par with 60 kg N ha⁻¹ comprising 75 % N through urea + 25 % N through FYM (3.627 t ha⁻¹). All other treatment combinations produced significantly less grain yield. Among N levels, application of 90 kg N ha⁻¹ recorded the maximum straw yield of 4.401 t ha⁻¹ and proved significantly superior to other N

Table 10. Effect of levels and sources of nitrogen on yield attributes of black rice

Treatment	Panicle m ⁻²	Panicle length (cm)	Filled grains/panicle	1000 grain weight (g)
Nitrogen levels (kg ha⁻¹)				
L ₁ - 30	274	20.7	70.5	23.90
L ₂ - 60	291	23.0	77.2	25.29
L ₃ - 90	292	23.1	79.1	25.78
SEm±	2.82	0.44	1.62	0.15
CD (<i>p</i> = 0.05)	11.1	1.7	6.4	0.58
Sources of nitrogen				
S ₁ - Urea (100 % N)	284	21.9	77.6	24.92
S ₂ - FYM (100 % N)	275	21.9	77.1	24.90
S ₃ - Urea (75 % N) + FYM (25 % N)	295	23.1	78.9	26.12
S ₄ - Urea (50 % N) + FYM (50 % N)	289	23.1	72.9	24.95
S ₅ - Urea (25 % N) + FYM (75 % N)	285	22.5	71.6	24.05
SEm±	6.30	21.9	1.79	0.14
CD (<i>p</i> = 0.05)	18.4	NS	5.2	0.42

DAT: Days after transplanting; FYM: Farmyard manure; SEm±:Standard error of mean; CD: Critical difference.

Table 11. Effect of levels and sources of nitrogen on grain and straw yield and harvest index of black rice

Treatment	S ₁	S ₂	S ₃	S ₄	S ₅	Mean
Grain yield (t ha⁻¹)						
Nitrogen levels (kg ha⁻¹)						
L ₁ - 30	2.306	2.623	2.817	2.746	2.535	2.606
L ₂ - 60	2.940	2.694	3.627	3.116	2.993	3.081
L ₃ - 90	3.345	2.535	4.137	3.292	3.169	3.292
Mean	2.870	2.623	3.539	3.046	2.887	2.993
Main / interaction	L	S	LXS	SXL		
SEm±	0.113	0.081	0.218	0.141		
CD (<i>p</i> = 0.05)	0.445	0.238	0.738	0.412		
Straw yield (t ha⁻¹)						
L ₁ - 30	2.799	2.923	3.680	3.398	3.081	3.169
L ₂ - 60	3.468	3.592	4.454	3.803	3.926	3.856
L ₃ - 90	4.225	3.363	4.912	4.771	4.173	4.401
Mean	3.486	3.292	4.525	3.979	3.732	3.803
Main / interaction	L	S	LXS	SXL		
SEm±	0.118	0.097	0.246	0.167		
CD (<i>p</i> = 0.05)	0.461	0.282	0.812	0.489		
Harvest Index (%)						
L ₁ - 30	45.12	47.37	43.37	44.69	45.10	45.13
L ₂ - 60	45.98	42.84	44.91	45.02	43.24	44.40
L ₃ - 90	44.24	42.94	45.68	40.87	43.04	43.35
Mean	45.11	44.38	44.66	43.53	43.79	44.29
Main / interaction	L	S	LXS	SXL		
SEm±	0.25	0.46	0.97	0.79		
CD (<i>p</i> = 0.05)	0.97	NS	2.94	2.32		

S₁: FYM (100 % N); S₂: FYM (100 % N); S₃: Urea (75 % N) + FYM (25 % N); S₄: Urea (50 % N) + FYM (50 % N); S₅: Urea (25 % N) + FYM (75 % N); LXS: Levels in same or different levels of nitrogen sources; SXL: Nitrogen sources in same nitrogen level.

levels. Among sources of N, application of 75 % N through urea + 25 % N through FYM produced the maximum straw yield of 4.525 t ha⁻¹ and proved significantly superior to all other sources of N. Interaction effects of levels and sources were significant on straw yield ha⁻¹. Application of 90 kg N ha⁻¹ comprising 75 % N through urea + 25 % N through FYM produced the maximum straw yield of 4.912 t ha⁻¹, being at par with L₂S₃ (4.454 t ha⁻¹). All other treatment combinations produced significantly less straw yield. Among N levels, application of 30 kg N ha⁻¹ recorded the maximum harvest index (HI) of 45.13 %, matching that of 60 kg N ha⁻¹ (44.40 %). The maximum level of 90 kg N ha⁻¹ was associated with a significantly lower HI. All the N sources recorded statistically similar HI values. The interaction effect of N levels and sources on the HI was significant. Application of 30 kg N ha⁻¹ through FYM recorded the maximum HI of 47.37 %, being at par with L₁S₁, L₁S₄ and L₁S₅.

Discussion

Crop growth and development

The delay in the attainment of phenophases at higher N levels (Fig. 2) is attributed to a longer vegetative growth stage, promoted by improved N availability and a slower transition to the reproductive phase. Application of N increases the days to flowering and prolongs the duration of flowering (30). The decline in LAI after 75 DAT was due to the migration of reserve food from leaves to reproductive organs and the onset of leaf senescence. Increase in value of growth parameters viz. PH, tillers per square meter, LAI and dry matter accumulation with increase in N levels up to 90 kg N ha⁻¹ and statistical parity between 60 and 90 kg N ha⁻¹ underscores the contribution of the element to crop growth. Nitrogen, as a component of protein, ensured adequate availability of the element at higher N fertilization levels, promoting protein synthesis and

augmenting plant growth. Many researchers have reported increases in PH (16, 17), tiller density (15, 16), LAI (17) and biomass (16) with increasing N levels. The decline in tillers per square meter after 50 DAT was due to the mortality of late-formed tillers caused by the diversion of photosynthates from vegetative parts to reproductive parts (panicle). Higher PH, tillers per square meter, LAI and component-wise and whole plant biomass with combinations of inorganic and organic sources of N at different growth stages than 100 % N through urea alone or 100 % N through FYM alone was due to the ready supply of N from inorganic sources and steady release from organic sources to meet N demand at various crop stages. The application of 100% N through FYM alone resulted in the lowest number of tillers per square meter at all stages due to slow mineralization of the organic source and inadequate supply to meet crop demand. Application of 100 % N through urea could increase tiller per square meter to some extent compared with 100 % N through FYM alone, due to the faster release of N, which meets critical demand at the active tillering stage. Earlier, research workers have reported the maximum PH (180.2 cm) and tillers per hill (12.7) with application of 50 % N (organic) + 50 % N (inorganic) under mid hill of Meghalaya (20) and the maximum tillers per hill (8.33) at Mymensingh, Bangladesh in black rice (26).

Biomass partitioning

In general, biomass accumulation in plants follows a sigmoid curve, marked by slow growth at early stages (lag phase), followed by a rapid hike during mid-stages (log phase) and a slower growth rate at terminal phases as the plant matures or senesces, with partitioning of biomass to specific plant parts. Thus, biomass accumulation in a specific plant part differs from that of the whole plant. The crop accumulated photosynthates in vegetative parts (leaf and stem/culm) at 25 and 50 DAT, with higher accumulation in leaf than stem at 25 DAT and stem than leaf at 50 DAT (Fig. 3 and 4). Higher partitioning of assimilates to leaves than to stems at the vegetative stage and to stems than to leaves at the panicle initiation stage, was reported earlier (31). Besides the vegetative parts, the photosynthates were additionally partitioned to the developing panicle at 75 DAT (Fig. 5) with leaf, stem and panicle shares of 26, 46 and 28 %, respectively. The leaf, stem and panicle shares changed to 13, 42 and 45 % at 100 DAT and 10, 35 and 55 % at PM, consequent to an increase in panicle share (Fig. 6 and 7). Earlier researchers have reported that photosynthates continue to be partitioned between leaves and stems until heading and flowering, respectively (32). Decrease in leaf share after 50–75 DAT (Fig. 8) was due to the onset of leaf senescence and remobilization to sink (panicle). The decrease in stem share towards the terminal stages (Fig. 9) was due to the remobilization of stored carbohydrates to grain and the mortality of late-formed tillers. Continuation of biomass partitioning to leaf, stem and root till heading, flowering, and ripening phases, respectively, has been reported earlier (33). Biomass partitioning to panicle continued until PM (Fig. 10). The maximum biomass accumulation by the crop under L2S1 at 25 DAT and L3S1 at 50 DAT was due to better growth under the chemical source, which provided N readily to the crop. The maximum biomass accumulation under L₂S₄, L₃S₃ and L3S4 at 75 DAT, L3S3 at 100 DAT and L₃S₃ at PM established the superiority of integrated N supply systems over chemical (32) or organic sources alone. The maximum total and plant-part-wise biomass accumulation with Urea (75 % N) + FYM (25 % N), irrespective of levels, was due to an adequate and sustained supply of N to the crop and higher photosynthetic and physiological

efficiency (34). Among levels of N, 60 and 90 kg N ha⁻¹ exceeded 30 kg N ha⁻¹, due to adequate availability of N to the crop. Nitrogen adequacy determines N partitioning and grain production efficiency. Pre-anthesis N accumulation supported high chlorophyll synthesis and photosynthetic efficiency, while post-anthesis N accumulation promoted grain development (35). Among the sources, S₃ excelled over the others in the 2 terminal stages of observation, due to the ready supply of N from the chemical source and the steady supply from the slow-releasing organic source (36). Partitioning of assimilates to the panicle (sink) is the major focus in rice production and depends on the remobilization of stored carbohydrates and on current photosynthate production. This requires source longevity and efficient sink unloading (37), which are ensured by an integrated supply of adequate N from both inorganic and organic sources. The significantly higher share of panicle biomass under treatments involving 60 and 90 kg N ha⁻¹ than those involving 30 kg N ha⁻¹ (Fig. 11) was due to fulfilment of crop N need and improvement in grain (sink) development.

Yield attributes

Higher values of yield attributes at 60 and 90 kg ha⁻¹ were due to adequate N availability and superior growth parameters. A higher number of effective tillers per square meter (240), the maximum panicle length (21.2 cm), grains per panicle (158) and filled grains per panicle (147) in black rice with a higher level of N (150 kg ha⁻¹) have been reported earlier (15). The maximum values of yield attributes with 75 % N through urea + 25 % N through FYM were due to the treatment's efficacy in ensuring a sustained supply of adequate N during crop growth. The maximum number of panicles per hill (17.71) and test weight of 1000 grains (27.96 g) with the application of 50 % N as organic + 50 % N as inorganic have been reported earlier (20). Application of 75 % N through inorganic fertiliser + 25 % N through cow dung manure produced the maximum effective tillers hill⁻¹ (7.3), panicle length (25.9 cm), spikelets panicle⁻¹ (22.87) and grains panicle⁻¹ (129.7) in black rice grown at Mymensingh, Bangladesh (26).

Yield

Grain yield is functionally related to yield attributes. In the present experiment, application of both 60 and 90 kg N ha⁻¹ resulted in higher grain yield than 30 kg N ha⁻¹, due to the efficacy of the 2 higher levels in supporting better crop growth parameters and yield attributes, ultimately resulting in higher grain yield. Earlier, the maximum black rice grain yield of 4298 kg ha⁻¹ and straw yield of 5361 kg ha⁻¹ were achieved with the application of 150 kg N ha⁻¹ at Bapatla, India (10). The maximum grain yield (5.67 t ha⁻¹) from 'Chakhao Poiraiton' black rice was reported with application of 80 kg N ha⁻¹ and both 70 and 60 kg N ha⁻¹ recorded statistically similar grain yield at Prayagraj, India (16). The maximum grain yield of 3.539 t ha⁻¹, achieved with 75 % N applied as urea and 25 % N applied as FYM, was due to improved soil structure and microbial activity under the treatment, leading to a sustained supply of N to the crop throughout the growth period. This contributed to superior growth parameters, yield attributes and ultimately yield of grain and straw. The maximum grain yield of 1.29 t ha⁻¹ was recorded with 50 % N organic + 50 % N inorganic under the mid-hill conditions of Meghalaya (20). The maximum grain (4795 kg ha⁻¹) and straw yields (5699 kg ha⁻¹) of black rice were achieved with a treatment that received 50 % recommended dose of nitrogen (RDN) through neem cake and 50 % RDN through urea at Bapatla, India. Integrated nutrient management practices, viz., 50 % RDN through vermicompost +

50 % RDN through urea with grain yield of 4660 kg ha⁻¹ and straw yield of 5275 kg ha⁻¹ and 50 % RDN through FYM + 50 % RDN through urea with grain yield of 4640 kg ha⁻¹ and straw yield of 5275 kg ha⁻¹ were at par. Application of 100 % RDN (organic) recorded less grain (2990 kg ha⁻¹) and straw (4022 kg ha⁻¹) yield (38).

Conclusion

We conducted this trial to optimise N management for proper growth and development, balanced biomass partitioning across stages and higher yield of black rice under the agroecological conditions of coastal Odisha in Eastern India. Application of 60 and 90 kg N ha⁻¹ with Urea (75 % N) + FYM (25 % N) produced statistically similar yield of grain and straw and proved superior to other treatments, but 45 kg N ha⁻¹ through urea + 15 kg N ha⁻¹ through FYM saved nitrogenous fertiliser to the extent of one-third without sacrificing yield and hence, can be adjudged as optimum.

Acknowledgements

The financial and administrative support provided by the authorities of Siksha 'O' Anusandhan (Deemed to be) University, Bhubaneswar, for conducting the field experiment and laboratory analysis is duly acknowledged.

Authors' contributions

SN carried out the field trial, recorded data, conducted laboratory analysis and prepared the manuscript. SDB conducted statistical analysis and reviewed the manuscript, while JJ prepared the figures and BB planned and monitored the experiment. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors do not have any conflicts of interest to declare.

Ethical issues: None

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