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Effect of Irrigation and Nitrogen Application at Early Tillering, Panicle Initiation and Flowering Stages on the Yield and Yield Attributes of Boro Rice

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Authors' contributions

This work was carried out in collaboration between both authors. Author MMU was responsible for data collection, data analysis and writing of the manuscript. Author MAR contributed to the conceptualization and designing of the experiment, reviewed and edited the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

The study aimed to evaluate the impact of irrigation scheduling and nitrogen splitting on the yield and yield attributes of boro rice, with particular emphasis on critical growth stages including early tillering, panicle initiation and flowering stages. The experiment was executed at the Agronomy Field Laboratory of the Department of Agronomy and Agricultural Extension, University of Rajshahi, from December 2022 to May 2023. The experiment setup was demonstrated using a split plot design,

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incorporating three replications. Two factors were determined for the experiment: the first included three different watering schedules aiming critical growth stages: early tillering (I_1), early tillering and flowering (I_2), and early tillering, panicle initiation and flowering panicle initiation (I_3). The second factor was distinct nitrogen splitting techniques, which consisted of four levels: control (N_0), 138 kg N ha^{-1} as basal (N_1), 69 kg N ha^{-1} at early tillering and flowering stages (N_2), and 46 kg N ha^{-1} at early tillering, panicle initiation and flowering stages (N_3). The highest reading of chlorophyll content was noticed in I_3 along with productive tillers (15.67), grains (115.25) and yield outcome (4.44 t ha^{-1}). Regarding nitrogen application, the greatest chlorophyll content, number of functional tillers (13.32), productive grains (112.44) panicle^{-1} and grain yield (4.48 t ha^{-1}) was recorded in treatment N_3. Therefore, the research finding suggest that the application of water at early tillering, panicle initiation and flowering stages along with the application of 46 kg N ha^{-1} will be helpful to maximize the production of rice in drought prone areas. This approach not only maximizes yield but also helps to mitigate water wastages associated with excessive irrigation.

Keywords: Irrigation; nitrogen; rice; yield; chlorophyll.

1. INTRODUCTION

Bangladesh is primarily an agrarian nation where agriculture is the main propellant of economic growth. While food and nutritional security is considered in its fullest sense yet to be achieved for 165 million people, major progress is being imposed upon rice production, as the staple food is rice [1]. Bangladesh is the third-largest producer of rice worldwide [2]. Over 13 million farms currently cultivate rice on 10.5 million hectares of land, constituting 80% of the land under irrigation and 75% of the total cropped area [3]. Based on nutritional analysis, a total of 100 grams of white, short-grain cooked rice contains 130 calorie intake, 28.7 grams of carbohydrates, 2.36 grams of protein content, and 0.19 grams of fatty tissue [4], which fulfill the maximum nutritional demand of Bangladesh's people.

Irrigation is vital for rice cultivation, as rice consumes 70% of agricultural sector water in Bangladesh [5]. The depletion of groundwater in Bangladesh resulting from overuse of irrigation water has emerged as a significant issue, particularly in the North-Western part [6]. Temperature rise, erratic rainfall patterns due to climate change result in more groundwater evaporation and raise the amount of water needed for industrial, agricultural, and other uses. However, water requirements in rice vary with different critical stages; water stresses during these stages decrease the yield severely. In order to provide food security for the expanding population and to withstand the effects of global warming, it is crucial to plan an effective and economical irrigation schedule in order to increase output. Nitrogen is the one most limiting necessary nutritional component of plants and a critical input for rice crop growth and yield [7]. It has been found that adding nitrogen increases yield and yield characteristics [8], as it is a functional component of proteins, amino acids, DNA, RNA and a number of phytohormones. Moreover, optimal nitrogen doses at critical stages induce cell division, proliferation and leaf elongation. On the other hand, overuse of nitrogen has a detrimental effect on the surrounding ecosystem, prevalence of diseases and insect pests increases agriculture and causes pollution in the aquatic ecosystem [9].

Boro rice, is a vital dry season crop in Bangladesh, plays a crucial role in ensuring food security due to its high yield potential. Irrigated boro boro rice occupied responsible for about 60% of total rice production covering 99.2% of the land during boro season, which fulfill over 52% of total food grain production [10,11]. Production of boro rice has significantly increased over the past decades, growing from 21.92 lac metric ton in 1971-1972 to 118.96 lac metric ton in 2021-22 [11]. However, based on historical data it is evident that rice cultivation trend is increasing throughout the country, more specifically Mymensingh, Rangpur, Bogura, Jashore, Rajshahi and Chattogram significantly contributed 13.9%, 9.8%, 8.6%, 8.6%, 8.2% and 8.0%, respectively of the total production [12]. Therefore, the study aimed to evaluate the effect of irrigation and nitrogen levels on the yield and yield attributes of boro rice.

2. EXPERIMENTAL DETAILS

2.1 Experimental Site and Soil

The test went on at the Agronomy Field Laboratory, Department of Agronomy and

Agricultural Extension, University of Rajshahi, all through the duration from November 2022 to May 2023, located 71 feet above sea level in latitude 24 22'36" N and longitude 88 38'27" E. The experimental site was located in a tropical climate, defined by high temperatures and moderate rainfall from April to September (Kharif season) and moderate temperatures from October to March (Robi season). The experimental soil had a pH of 8.1, 0.46% organic matter, 0.09% overall nitrogen, and the available phosphorus, potassium, sulphur and zinc are 17.61, 0.21, 9.36, and 0.33 µg g^{-1}, respectively. During the observation period, there was a mean of 17.309 mm of rainfall and 78.78% humidity.

2.2 Experimental Design and Treatment

The experiment was laid out in Split-Plot design with 3 replications. Two factors were identified: the first was the use of three watering timetables, specifically for early tillering stages (I_1), early tillering & flowering stages (I_2), and early tillering, panicle initiation & flowering stages (I_3); the second was the four splitting of nitrogen, control (N_0), 138 kg N ha^{-1} as basal application (N_1) , 69 kg N ha^{-1}at early tillering and flowering stage (N_2) and 46 kg N ha^{-1}at early tillering, panicle initiation and flowering stage (N_3).

2.3 Crop Husbandry

Thirty-five days old seedlings were transplanted in the well-puddled plots of three seedlings $hill^{-1}$ on 7th January 2023. Fertilizers were applied to the plot, including urea, Triple Super Phosphate (TSP), Muriate of Potash (MoP), gypsum, and zinc sulphate, with quantities of 300, 100, 80, 60, and 10 kg ha^{-1}, respectively. With the exception of urea, this fertilizer was applied as a basal dose during the final land preparation of individual plots. The total specified amount of urea was applied according to experimental requirements.

2.4 Data Collection and Analysis

Data were collected with consideration of critical stages. To measure chlorophyll content, SPAD (Soil and Plant Analyzer Development) 502 Plus Chlorophyll Meter was used. Recorded data for plant height, tillers number, yield status were compiled and tabulated in proper form for statistical analysis. The “Analysis of Variance (ANOVA)’’ was done with the help of the computer package MSTAT-C. The mean differences and Duncan’s Multiple Range Test (DMRT) were judged by IBM SPSS software.

3. RESULTS AND DISCUSSION

3.1 Effects on Plant Characters

3.1.1 Effect of irrigation frequencies on chlorophyll content

SPAD values showed a significant correlation with chlorophyll content. The highest measurements (31.760, 38.348 and 41.467 mg m^{-2}) were consistently recorded in I_3 (Fig. 1), while I_1 exhibited lower values (26.522, 35.786 and 37.759 mg m^{-2}) at 30, 50, and 70 DAT (Days after transplanting). Effective irrigation is well known to maintain optimum turgor pressure, allowing efficient absorption of nitrogen, a vital component of chlorophyll. Several studies have reported increased yield and agronomic efficiencies with appropriate nitrogen applications [13].

3.1.2 Effect of nitrogen levels on chlorophyll content

The results revealed notable variations when the impact of nitrogen on the amount of chlorophyll was considered. N_3 had the most levels (Fig. 2) of chlorophyll contents (30.286, 38.203 and 40.728 mg m^{-2}). Conversely, N_0 displayed the least results (27.791, 36.341, and 38.307 mg m^{-2}). Nitrogen is a fundamental element of the chlorophyll molecule, as a result, an adequate supply of nitrogen enhances the production of chlorophyll. Sarker et al. [14] reported that optimum doses of nitrogen in rice increase the chlorophyll content.

3.1.3 Interaction effect of irrigation frequencies and nitrogen levels on chlorophyll content

The amount of chlorophyll content was not being much affected by the combination of irrigation schedules and nitrogen concentrations (Table 1). However, I_1N_0 showed the lowest value at 25.627, 34.930, and 36.620 mg m^{-2}, whereas I_3N_3 (Irrigation and 46 kg N ha^{-1} application at early tillering, panicle initiation and flowering stages) showed the highest values (33.930, 39.493, and 43.867 mg m^{-2}). Furthermore, I_3N_2 (Irrigation at early tillering, panicle initiation and flowering stages and 46 kg N ha^{-1} at early tillering and panicle initiation stages) showed the second-highest values (31.700, 38.400, and 41.700 mg m^{-2}).

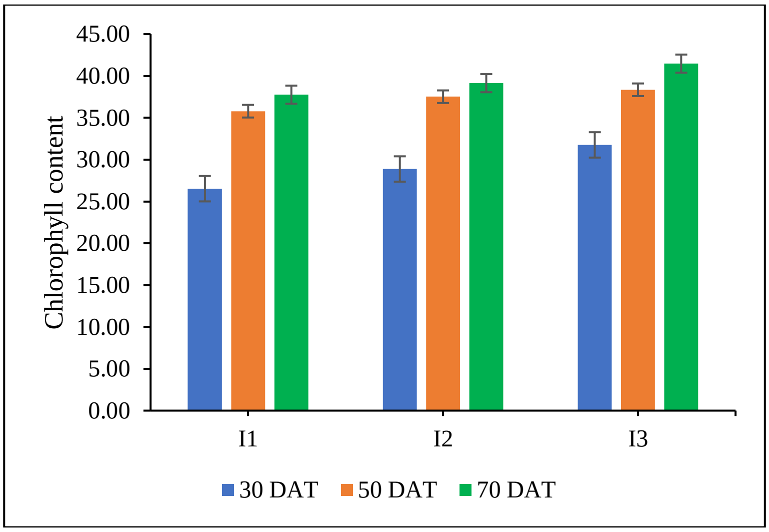

Fig. 1. Effect of irrigation frequencies on chlorophyll content

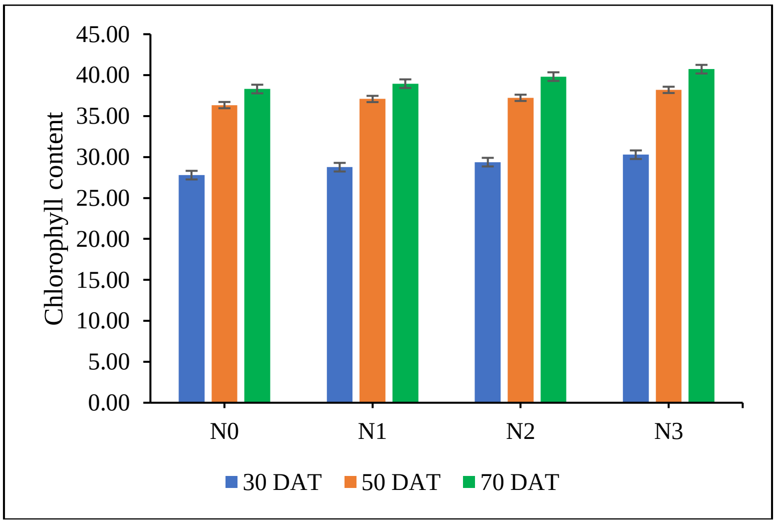

Fig. 2. Effect of nitrogen on chlorophyll content at different DAT

Table 1. Interaction effect of irrigation frequencies & nitrogen levels on chlorophyll content

Treatment	**Chlorophyll content**		
	30 DAT	**50 DAT**	**70 DAT**
I_1N_0	25.627	34.930	36.620
I_1N_1	26.463	35.627	37.233
I_1N_2	26.867	36.133	38.267
I_1N_3	27.130	36.453	38.917
I_2N_0	27.800	37.130	38.733
I_2N_1	28.363	37.117	38.907
I_2N_2	29.563	37.163	39.500
I_2N_3	29.797	38.663	39.400
I_3N_0	29.947	36.963	39.567
I_3N_1	31.463	38.533	40.733
I_3N_2	31.700	38.400	41.700
I_3N_3	33.930	39.493	43.867
Level of significance	NS	NS	NS
CV (%)	**2.80**	**2.50**	**2.20**

Note: DAT= Days After Transplanting; NS = Non-Significant; CV = Coefficient of Variation

3.2 Effects on Yield and Yield Components of Boro Rice

3.2.1 Plant height (cm)

There was a direct connection between the inundating of fields at critical stages of crops and plant height. (Table 2). The results showed that I_3 (87.49 cm) was the growing medium for the largest plant, whereas I_1 (75.64 cm) was used for the smallest plant. I_2 (85.16 cm) was the second longest plant producing medium. Plant height was significantly changed by the watering according to the crop stage treatment ensuring the nutrients availability and proper root development, according to Mathew et al*.* [15].

Split nitrogen usages had a significant effect on plant height (Table 3). The most mature plant was raised in N_3 (84.94 cm) that was significant to N_2 (83.82), while the youngest plant was raised in N_0 (80.44 cm), per the results. Plant height is increased by nitrogen treatment, as reported by Paul et al. [6] and Hoque et al*.* [16]. Additionally, Ferdush et al. [9] reported that nitrogen application increases the cell division and elongation resulting in the enhancement of plant height. However, the interaction of I_3 with N_3, yielding the largest plant height (90.33 cm) (Table 4).

3.2.2 Total number of tillers hill^{-1}

The total number of rice tillers per hill^{-1} varied significantly according to the moistening frequency (Table 2). The results showed that I_3 (17.20), which is scientifically equivalent to I_2 (14.82), had the highest number of tillers hill^{-1}, while I_1 (12.52) had the lowest. Consistent and adequate supply of water induces the formation of lateral buds, which develop into new tillers. Moreover, irrigation the during tillering stage ensures the needed resources to produce more tillers. Similar results were confirmed by Haque et al*.* [17].

Significant differences were seen in the total number of boro rice tillers hill^{-1} as a result of the fractionate nitrogen treatment (Table 3). The results showed that the largest number of tillers hill^{-1} was recorded in N_3 (16.33), and the second highest was from N_2 (12.36), while the least number of tillers hill^{-1} was identified in N_0 (13.59), and this is equivalent to N_1 (14.22) statistically. Highest number of total tillers occurred due to absorption of nutrients, moisture and for more availability of sunlight throughout the growing season [2]. Similar outcomes were noted by Pooja et al*.* [18] and Hoque et al*.* [19].

There was numerically a large fluctuation of tillers hill^{-1} of boro rice by a blend of hydration schedule and splitting of N (Table 4). The results showed that when I_3 reacted with N_3, the greatest tillers hill^{-1} (18.83) was recorded, and when it interacted with N_0, the least number of tillers hill^{-1} (11.66) was documented in I_1. Kumawat et al*.* [20] noted analogous results.

3.2.3 No. of functional tillers hill^{-1}

Moisturizing with consideration of crop physiological stages has a significant impact on functional tillers (Table 2). The results showed that I_3 (15.67) had the highest number of functional tillers hill^{-1}, which is operationally identical to I_2 (11.98), while I_1 (9.17) had the lowest number. Optimum water supply increases the nutrients availability, reduces the water stress, and ensures proper root development. Miah et al*.* [21] used different irrigation techniques and reported that application of irrigation at panicle initiation stage increases functional tillers.

The capabilities of tillers hill^{-1} had a major impact by nitrogen splitting (Table 3). The results showed that N_0 (11.42) had the fewest functional tillers hill^{-1}, while N_3 (13.32) had the largest that was significant to N_2 (12.36). Application of nitrogen at tillering stage ensures better synthesis of amino acids, proteins and enzymes which are responsible to produce effective tillers in rice. When nitrogen was applied in a divided way, Liu et al*.* [22] saw similar results.

Pairing of watering schedule and separation of nitrogen had significant consequences on operational tillers hill^{-1} (Table 4). The results showed that when it interacted with N_3, I_3 had the forefront functional tillers hill^{-1} (16.97), and when it interacted with N_0, I_1 had the lowest number of functional tillers hill^{-1} (9.07). Similar findings were observed by Li et al*.* [23] through an examination of the connection between nitrogen splitting and watering levels.

3.2.4 Spike length (cm)

It was demonstrated that the spike length had a significant impact on the watering treatment (Table 2). The greatest spike length (22.96 cm) was found in I_3, which is statistically equivalent to I_2's 22.16 cm. I_1 had the fewest spike lengths (21.54 cm) observed.

Table 2. Effect of irrigation frequencies on yield contributing characters of boro rice

Treatment	Plant height (cm)	No of total tillers	No of effective tillers	Panicle length
I_1	75.642c	12.522c	9.167c	21.535b
I_2	85.158b	14.825b	11.983b	22.156ab
I_3	87.492a	17.200a	15.667a	22.959a
Level of significance	0.01	0.01	0.01	0.05
CV (%)	**1.03**	**3.41**	**3.97**	**6.30**

Note: "In each column, treatment means followed by the same letter (e.g., a, b) are not significantly different from each other at the 5% level of significance according to Duncan's Multiple Range Test (DMRT). Means with different letters indicate significant differences. NS = Non-Significant; CV = Coefficient of Variation

Table 3. Effect of nitrogen on yield and yield contributing characters of boro rice

Treatment	Plant height	No of total tillers	No of effective tillers	Panicle length
N_0	80.444d	13.585d	11.422c	20.348b
N_1	81.844c	14.222c	11.989b	22.345a
N_2	83.822b	15.256b	12.356b	22.691a
N_3	84.944a	16.333a	13.322a	23.482a
Level of significance	0.01	0.01	0.01	0.01
CV (%)	**1.03**	**3.41**	**3.97**	**6.30**

Note: "In each column, treatment means followed by the same letter (e.g., a, b) are not significantly different from each other at the 5% level of significance according to Duncan's Multiple Range Test (DMRT). Means with different letters indicate significant differences. NS = Non-Significant; CV = Coefficient of Variation.

Table 4. Interaction effect of irrigation and nitrogen on yield and yield contributing characters of boro rice

Interaction	Plant height	No of total tillers	No of effective tillers	Panicle length	No. of Grains panicle^{-1}	No. of filled grain panicle^{-1}
I_1N_0	72.200g	11.656	9.067g	19.878	91.67k	72.29j
I_1N_1	75.267f	12.333	9.033g	21.666	96.22j	74.17j
I_1N_2	77.767e	12.767	8.733g	22.041	103.78hi	78.33i
I_1N_3	77.333e	14.167	9.833fg	22.556	102.72i	85.17gh
I_2N_0	83.500d	14.744	11.100ef	20.267	107.56gh	82.83h
I_2N_1	83.467d	15.011	11.667de	22.589	111.06fg	88.39fg
I_2N_2	86.500bc	15.400	12.000de	22.622	118.89cd	96.11e
I_2N_3	87.167b	16.833	13.167cd	23.145	121.89c	116.67c
I_3N_0	85.633c	16.489	14.100bc	20.900	114.33ef	88.56f
I_3N_1	86.800bc	16.667	15.267ab	22.779	117.17de	109.22d
I_3N_2	87.200b	17.600	16.333a	23.411	131.67b	127.67b
I_3N_3	90.333a	18.833	16.967a	24.745	141.11a	135.50a
Level of significance	0.01	NS	0.01	NS	0.01	0.01
CV (%)	**1.03**	**3.41**	**3.97**	**6.30**	**1.89**	**2.22**

Note: "In each column, treatment means followed by the same letter (e.g., a, b) are not significantly different from each other at the 5% level of significance according to Duncan's Multiple Range Test (DMRT). Means with different letters indicate significant differences. NS = Non-Significant; CV = Coefficient of Variation

The spike length had a discernible impact on the splitting of nitrogen (Table 3). N_3 had the longest spike length, measuring 23.48 cm, while N_0 had the least spike length, assessed at 20.35 cm. Optimum application of nitrogen at panicle initiation stage assists the cell division of spikelet tissues resulting in increased spike length. Gewaily et al. [16] reported similar outcomes with split nitrogen application.

When considering the interplay between the nitrogen splitting and the hydration schedule, spike length was not found to have a significant impact (Table 4). When it interacted with N_3, I_3 reported the longest spike length (24.7 cm), while I_1 estimated the shortest spike length (19.88 cm) when it interacted with N_0. According to Keerthi et al. [24], an irrigation schedule and split nitrogen application boosted spike length.

3.2.5 No. of grains spike^{-1}

It was discovered that the quantity of grains spike^{-1} significantly affected when to water, (Table 5). I_3 displayed the greatest number of grain spike^{-1} (126.07), while I_1 displayed the lowest number of grains spike^{-1} (98.60). I_2 demonstrated the second highest (114.85). Optimum irrigation supply at the panicle initiation stage supports panicle formation, nutrient uptake and providing energy needed for grainss production, resulting in more grains per panicle. Barman et al. [25] found that increasing the frequency of watering significantly increased the overall amount of grain production.

Grains spike^{-1} was found to have a significant influence on nitrogen splitting (Table 6). Regarding the leading grains spike^{-1}, its value in N_3 was (121.91), where N_2 demonstrated (118.11). In N_0, the fewest number of grains spike^{-1} (104.52) was found. This is because nitrogen supports the spikelet's initiation, ensuring optimal nutrients supply and increment of photosynthetic activity.

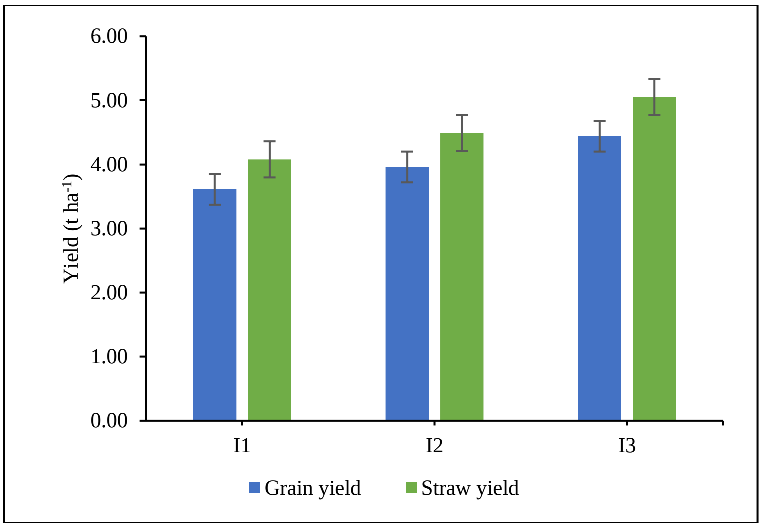

Fig. 3. Effect of irrigation frequencies on the grain and straw yield

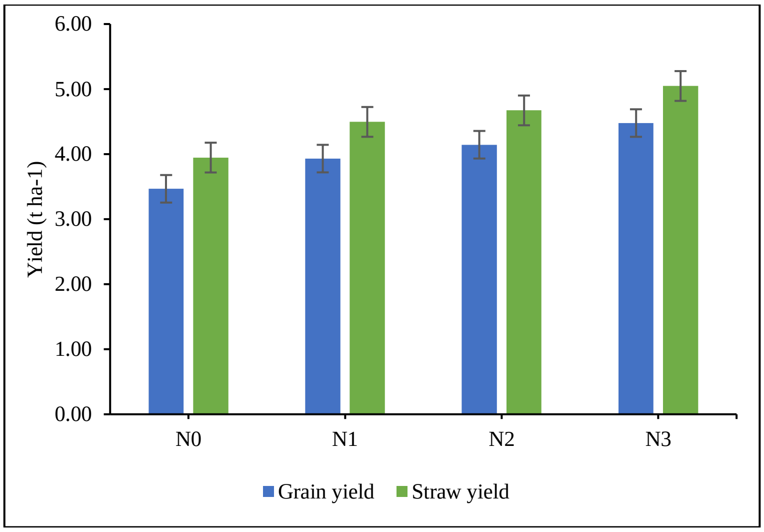

Fig. 4. Effect of nitrogen levels on grain and straw yield

Table 5. Effect of irrigation frequencies on yield contributing characters of boro rice

Treatment	No. of grains panicle^{-1}	No. of filled grains panicle^{-1}	1000 Grains weight	Biological yield (t ha^{-1})	Harvest Index (%)
I_1	98.60c	77.49c	21.217b	7.6917c	46.963
I_2	114.85b	96.00b	21.283b	8.4517b	46.796
I_3	126.07a	115.24a	21.675a	9.4931a	46.828
Level of significance	0.01	0.01	0.05	0.01	NS
CV (%)	1.89	2.22	3.06	6.03	1.37

Note: "In each column, treatment means followed by the same letter (e.g., a, b) are not significantly different from each other at the 5% level of significance according to Duncan's Multiple Range Test (DMRT). Means with different letters indicate significant differences. NS = Non-significant; CV = Coefficient of Variation

Table 6. Effect of nitrogen on yield and yield contributing characters of boro rice

Treatment	No. of grains panicle^{-1}	No. of filled grains panicle^{-1}	1000 grains weight	Biological yield (t ha^{-1})	Harvest Index (%)
N_0	104.52d	81.23d	20.178c	7.413c	46.735
N_1	108.15c	90.59c	21.489b	8.427b	46.660
N_2	118.11b	100.70b	21.511b	8.817b	47.013
N_3	121.91a	112.44a	22.389a	9.525a	47.041
Level of significance	0.01	0.01	0.01	0.01	NS
CV (%)	1.89	2.22	3.06	6.03	1.37

Note: "In each column, treatment means followed by the same letter (e.g., a, b) are not significantly different from each other at the 5% level of significance according to Duncan's Multiple Range Test (DMRT). Means with different letters indicate significant differences. NS = Non-Significant; CV = Coefficient of Variation.

Table 7. Interaction effect of irrigation and nitrogen on yield and yield contributing characters of boro rice

Interaction	1000 grain weight	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest Index (%)
I_1N_0	19.733	3.150	3.560	6.710	46.948ab
I_1N_1	21.500	3.4000	3.887	7.287	46.672ab
I_1N_2	21.733	3.700	4.160	7.860	47.086ab
I_1N_3	21.900	4.2000	4.710	8.910	47.147ab
I_2N_0	20.300	3.3500	3.973	7.323	45.753 b
I_2N_1	21.467	3.8267	4.363	8.190	46.721ab
I_2N_2	21.000	4.3000	4.817	9.117	47.163a
I_2N_3	22.367	4.3667	4.810	9.177	47.546a
I_3N_0	20.500	3.9000	4.307	8.207	47.505a
I_3N_1	21.500	4.5667	5.237	9.803	46.588ab
I_3N_2	21.800	4.4333	5.040	9.473	46.788ab
I_3N_3	22.900	4.8667	5.623	10.489	46.431ab
Level of significance	NS	NS	NS	NS	0.05
CV (%)	3.06	6.28	6.09	6.03	1.37

Note: "In each column, treatment means followed by the same letter (e.g., a, b) are not significantly different from each other at the 5% level of significance according to Duncan's Multiple Range Test (DMRT). Means with different letters indicate significant differences. NS = Non-Significant; CV = Coefficient of Variation

The analysis revealed that grains spike^{-1} had a significant influence on the link between the nitrogen splitting process and the (Table 4). Moreover, when watering sequences (I_3)

interacted with N_3, the peak of the grains spike^{-1} (141.11) was calculated, and when it interacted with N_0, the lowest grains spike^{-1} (91.67) was computed in I_1. According to research by Keerthi et al. [24] and Kumawat et al. [20], grains spike^{-1} was raised by suitable watering intervals and nitrogen splitting.

3.2.6 No. of filled grains spike^{-1}

The timetable of saturating has a considerable effect on the quantity of packed grains spike^{-1}. I_3 had the biggest full grains spike^{-1} (115.24), which was comparable to I_2 (96.00), and I_1 had the lowest (77.49) (Table 5). This is because water facilities maintain turgor pressure and increase photosynthesis activity, providing the energy to transport photosynthates to sink from source. Additionally, water stress is minimized through application of water, which reduces the abortion of grains and thus increases the filled grains number. Mathew et al. [15] reported that watering at panicle initiation stage greatly increases filled grains.

A considerable impact of nitrogen fractionalization was reported on grain-filled spike^{-1} (Table 6). The highest number of grains that filled spike^{-1} (112.44) was determined from N_3, whereas the fewest packed grains spike^{-1} (81.23) was estimated from N_0. N_2 produced the second highest (100.70) number of filled grains. Productive grains per panicle increased with the increment of nitrogen levels because it enhances the spikelet development and optimized the grain filling process. Similar results were found in the split nitrogen utilization by Pooja et al. [18].

The combined effect of the hydration and split nitrogen treatment varied significantly on the packed grain spike^{-1} of rice, as shown in Table 4. In the cooperation of I_3N_3, the most occupied grain spike^{-1} (135.50) was estimated, while the interaction of I_1N_0 produced the fewest, which was (72.29). Keerthi et al. [24] noted comparable results.

3.2.7 1000 grain weight (g)

Regarding the weight of one thousand grains of boro rice, there was a discernible difference in the rewetting timings (Table 5). It was noted that I_3 had the highest test weight of 21.68 g, while I_1 had the lowest test weight of 21.22 g. Many hydration timings significantly raised the test weight [26] and [25].

Nitrogen split utilization had a notable bearing on the total weight of one thousand grains of boro rice on BRRI dhan28 (Table 6). N_0 had the lowest test weight of 20.18 g, while N_3 had the highest test weight of 22.39 g. The main cause of a rise in the grain's weight at greater nitrogen levels may be the leaves increased chlorophyll level resulting in raised the rate of photosynthetic activity, as a result, produced an abundance of photosynthates for grain formation [4]. Similarly, Kamruzzaman et al. [27] noted their observations.

The weight of the thousand grains was not significantly affected by the interaction between the timing of watering and the N splitting (Table 7). I_3N_3 had the biggest weight of thousand grains (22.90 g), whereas I_1N_0 had the smallest weight (19.73 g). The same conclusions were reached by Keerthi et al. [24] and Pooja et al. [18].

3.2.8 Grain yield (t ha^{-1})

Data indicate that the methods used for scheduling irrigation have a significant impact on grain output. The I_3 provided the largest (Fig. 3) number of grains (4.44 t ha^{-1}), while the I_1 yielded the fewest (3.61 t ha^{-1}). The treatment I_2 produced the second highest grain yield (3.96 t ha^{-1}). The work represented that the grain yield was gradually increased with the increase of watering frequencies. This is because of the consistent supply of nutrients throughout the growth period. Choudhary et al. [26] reported a similar result.

Studies demonstrate that grain yield is significantly impacted by nitrogen fragmentate. N_0 yielded the least amount (Fig. 4) of grain (3.47 t ha^{-1}), whereas N_3 produced the highest (4.48 t ha^{-1}). Whereas N_1 and N_2 produced 3.93 t ha^{-1} and 4.14 t ha^{-1}, respectively. The results showed that grain yield gradually increased in an order sequence from N_0 to N_3. Improvements in growth metrics, such as the average number of overall tillers hill^{-1}, as well as improvements in yield and yield-contributing characteristics, such as the amount of productive tillers hill^{-1} with the amount of grains panicle^{-1}, were primarily responsible for the rise in grain yield driven on by the higher nitrogen status. According to Kamruzzaman et al. [15], split nitrogen application enhanced grain production.

Research indicates that the relationship between nitrogen splitting and watering schedule had no significant impact on grain output (Table 7). The I_3 with N_3 was predicted to have the most grain (4.87 t ha^{-1}), whereas the I_1 with N_0 was estimated to have the least (3.56 t ha^{-1}). A suitable drenching calendar and divided nitrogen usage boosted grain production [27] and [20].

3.2.9 Straw yield (t ha^{-1})

The multiple watering induced the varied straw production (Fig. 3). It was projected that the I_3 had the highest straw yield (5.05 t ha^{-1}) of Boro rice and I_2 was the second one (4.49 t ha^{-1}), while the I_1 had the lowest (4.08 t ha^{-1}). Watering at different critical stages helps to increase leaves and tillers number resulting in higher straw yield. Barman et al. [25] and Karim et al. [28] discovered comparable results while using multiple watering techniques had the highest straw yield.

Studies demonstrate that grain yield is significantly impacted by nitrogen fragmentate. N_0 yielded the least amount (Fig. 4) of grain (3.47 t ha^{-1}), whereas N_3 produced the highest (4.48 t ha^{-1}). Whereas N_1 and N_2 produced 3.93 t ha^{-1} and 4.14 t ha^{-1}, respectively. The results showed that grain yield gradually increased in an order sequence from N_0 to N_3. Improvements in growth metrics, such as the average number of overall tillers $hill^{-1}$, as well as improvements in yield and yield-contributing characteristics, such as the amount of productive tillers $hill^{-1}$ with the amount of grains $panicle^{-1}$, were primarily responsible for the rise in grain yield driven on by the higher nitrogen status. According to Kamruzzaman et al. [27], split nitrogen application enhanced grain production.

Research indicates that the timing of watering and nitrogen splitting together was not a significant effect on the amount of straw produced, as shown in Table 7. The I_3 with N_3 recorded the highest straw yield (5.62 t ha^{-1}), whereas the I_1 with N_0 projected the least value (3.56 t ha^{-1}). Kumawat et al. [20] discovered that straw output increased with the proper frequency of watering and divided nitrogen administration.

3.2.10 Biological yield (t ha^{-1})

The biological yield was significantly impacted by the timing and length of watering (Table 5). I_3 had the highest biological yield (9.49 t ha^{-1}), which was quantitatively equivalent to I_2's (8.45 t ha^{-1}). In contrast, I_1 produced the lowest biological yield (7.69 t ha^{-1}). Karim et al. [28] discovered that Alternative Wetting and Drying (AWD) results better when compared to conventional irrigation techniques.

The amount of nitrogen utilized in splits significantly affected biological yield (Table 6). The biological production from N_3 was predicted to be the highest at 9.53 t ha^{-1}. One the other hand, N_0 had the lowest biological yield (7.41 t ha^{-1}) at the same time. Rajput et al. [29] noticed that biological yield was enhance when they used split nitrogen. The cooperation of nitrogen splitting and hydration timing had no significant impact on biological yield (Table 7).

3.2.11 Harvest index (%)

The harvest index was not statistically significant because of the different watering timings (Table 5). It was observed that I_1 had the highest harvest index (46.96%), whereas I_2 had the lowest (46.79%) and I_3 produced the second ranked (46.83%).

The harvest index was significant when splitting of nitrogen and the watering schedule interacted (Table 6). With N_3, I_2 had the highest harvest index (47.55%), whereas I_2N_0 had the lowest (45.75%), according to estimates.

4. CONCLUSION

From the research, it was found that applying irrigation and 46 kg N ha^{-1} at the tillering stage, panicle initiation, and flowering stages (I_3 and N_3) yielded highest productive tillers, grains and grain output. Water scarcity is becoming more prevalent due to environmental degradation. Efficient water management considering the critical stages of rice not only will help to conserve the resources but also increase the yield of rice in water scare regions. Moreover, proper nitrogen application will prevent soil degradation and minimize environmental pollution, ensuring long term soil health. However, further research is necessary to evaluate the grains quality and associated cost of production.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The authors hereby disclose that no generative AI technologies were utilized in the creation or revising of this work, including text-to-image generators and large language models (ChatGPT, COPILOT, etc.).

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COMPETING OF INTERESTS

Authors have declared that no competing interests exist.

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