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Optimizing rate and time of nitrogen application for reducing nitrogen requirement and increasing productivity of wheat

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ABSTRACT

As per 4Rs nutrient stewardship, the right timing and right rate of nitrogen (N) are two important attentions for profitable and sustainable crop production, particularly in the N deficient soil. The effectiveness of N utilization depends on the appropriate timing and amount of N application as per the crop demands at the critical stages of crop growth. The experiment was carried out at the experimental field of Agrotechnology Discipline, Khulna University, Bangladesh during the winter season of 2019-20 to investigate into the effect of schedule and rates of N application on wheat growth, yield and profitability. The experimental treatments comprised three application schedules (66% at sowing and 34% at the 3-leaf stage; 50% at 3-leaf, 30% at jointing and 20% at the booting stage; 50% at 6-leaf stage, 30% at jointing and 20% at the booting stage) and three nitrogen rates (120, 92 and 80 kg ha^{-1}) with three replications. The yield attributes and yield of wheat were substantially affected by the schedule and rates of N application yet growth parameters were not significant. The highest grain yield, total dry matter, grains spike^{-1} and 1000-seed weight were achieved from the application of N @ 50% at 3-leaf, 30% at jointing and 20% at booting stages with 120 kg ha^{-1}. Statistically similar results were also attained by the same application schedule with a reduced rate of N (92 kg ha^{-1}) due to proper distribution based on the crop requirement on different growth stages rather than the usual practice with a higher rate of N. The maximum net return (BDT 50687) and benefit-cost ratio (1.62) were found in the application of 92 kg ha^{-1} N in three splits @ 50% at 3-leaf, 30% at jointing and 20% at booting stages. The findings of this study revealed that the right application schedule reduces 25% N requirement and increases the grain yield of wheat.

Keywords: N scheduling, N rate, grain yield, net income, wheat

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1 Introduction

The predicted growth in the world population from 7.4 billion in 2017 to 9.7 billion by 2050 is a major driver of global cereal demand (Fukase and Martin, 2020). Among the cereals, wheat is one of the most widely cultivated crops accounting one-third of the cultivable lands and plays a vital role in feeding ∼35% people of the world as a staple food and also provides more calories and proteins in the diet of the world people (IDRC, 2010; Li et al., 2016). In human diets throughout the world, wheat has been acknowledged as a significant source of protein due to its high protein level (Grewal and Goel, 2015) and more than half of the annually produced wheat is used for human consumption (Pequeno et al., 2021). Wheat production has made indisputable contributions to food security as a result of recent improvements in agronomic performance such as spike number, number of grains spike^{-1}, 1000-grain weight, and average grain yield for both winter and spring varieties (Qin et al., 2015; Si et al., 2020). Wheat is grown on approximately 216 million hectares around the world (almost 25% of the total global area devoted to cereal crops), with a total yearly production of over 765 million tons

(Pequeno et al., 2021). In Bangladesh, wheat is the second most extensively cultivated cereal next to rice, yet the cultivable area of wheat is 0.8 million hectares with the production of 1.9 million tons and the average yield is 3.30 t ha^{-1} (BBS, 2022) which are very low compared to other leading wheat growing countries. Europe produces most of it (Trnka et al., 2014) and the second largest producer is India (Joshi et al., 2007). However, limitations to the widespread cultivation of wheat in Bangladesh are linked to several biotic and abiotic factors including deficient nutrients in soils particularly N and lack of thoughtful nutrient management practices (Islam et al., 2018).

Among the nutrient elements, N is the most essential macronutrient for crop growth and development. Wheat is one of the most N demanding crops in comparison to other cereals (Ladha et al., 2005). The grain yield and quality of wheat largely depends on adequate supply of N (Efretuei et al., 2016). A small portion of applied N fertilizer is taken by the crops (33% for wheat) even though this element is considered as the key for increasing agricultural productivity worldwide (Raun and Johnson, 1999). In general, the response of a crop to applied N fertilizer is depends on soil type, soil fertility, crop variety, other soil-crop management practices (Rahman et al., 2011) and also the judicious N management strategies. In Bangladesh, the agricultural soils are mostly deficient in N and crop responds is noticeable to applied N. Application of N at right rate improve the grain yield of wheat by increasing the number of spikes, kernel spike^{-1} and grain size (Abedi et al., 2011; Si et al., 2020). Application of N lower than the optimum rate reduces the grain yield of wheat due to its deficiency while excess application had no significant yield benefit or may decrease the grain yield and lead to the increase of N losses ultimately increases the production cost. Crop growth and yield will be hampered if the soil available N is not supplemented with adequate applied fertilizer N (Efretuei et al., 2016). So, the N application efficiency in winter wheat is an important indicator for the balanced fertilization of N (Mandic et al., 2015).

After application of N fertilizer, the N in the soil will make available within 2-3 days and remains available for a short period (10-15 days). So, the applied N is no longer sufficient to meet the requirements of crops (Efretuei et al., 2016). The crop requirement of fertilizers N when the soil N become limiting, thus the timing of initial N application depends on the status of the available soil N. The N requirement of wheat starts from first day of life and continues until grain filling, thus appropriate timing of N at different splits is very much crucial to meet the crop N demand at different growth stages. N requirement of crops largely depends on the critical stages and any deficiency of N during these stages affects crop growth and productivity. The time and amount of N application mostly inclined with the status of soil available N (Efretuei et al., 2016). The application of N in split doses has been reported as more beneficial in most crops rather than the basal application of all N fertilizers (Rahman et al., 2011). In Bangladesh, the recommended rate of N fertilizer for wheat is 120 kg ha^{-1} of which two-thirds are applied as basal dose during final land preparation and rest one-third is applied as top dressing at three leaf stage reported as most efficient in improving grain yield of wheat (Azad et al., 2022). Appropriate timing of N application as per the crop demand improves the crop biomass, grain yield and NUE (Cui et al., 2010; Efretuei et al., 2016; Kostić et al., 2021). Application of N in three splits enhances the grain yield and N use efficiency of wheat rather than two splits and single application as basal (Rahman et al., 2011; Belete et al., 2018) . From the earlier study it is noticed that N application at earlier stages may reduce the grain yield compared to mid-season fertilization (Raun et al., 2002).

Appropriate time of N application and optimum rate are two important aspects for improving yield and nitrogen use efficiency, and also minimizing the losses of N (Rhezali and Lahlali, 2017). To improve the productivity and profitability of wheat cultivation, there is an urgent need to optimize the rate and time of nitrogen (N) application for sustainable agricultural management (Wang et al., 2011). Therefore, the present study was undertaken to evaluate the effect of rate and timing of N application on the N requirement, yield and profitability of wheat grown in the coastal region of southwestern Bangladesh.

2 Materials and Methods

2.1 Description of the experimental site

The experiment was conducted during winter (2019-20) at the research field of Agrotechnology Discipline, Khulna University, Bangladesh which is located at the Agro-ecological Zone of Gangetic Tidal Floodplain (AEZ-13) with latitude 22°47“ N and longitude 89°34” E under the sub-tropical climate. The area is characterized by low rainfall, low humidity, and a short day with short winter during the winter season (Rabi season). The field was medium highland with well-drained and silty clay loam in texture. The physicochemical properties of the experimental field soils are presented in Table 1. During the cultivation period, the lowest (13.8-24 °C) and highest (20.6-32.3 °C) monthly average temperatures were recorded in January and March, respectively (Fig. 1). The total rainfall during the growing season was ∼230 mm of which 175 mm occurred in November 2019 (Fig. 1).

Table 1. Physicochemical properties of the experimental soil before sowing of seeds

Parameters	Value	Status
Soil pH	8.10	Moderate
EC (dS m^{-1})	4.40	Low
Organic Matter (%)	1.85	Medium
Nitrogen (%)	0.11	Very Low
Phosphorus (μg g^{-1})	6.81	Very Low
Potassium (meq 100 g^{-1})	0.41	High
Sulphur (μg g^{-1})	40.2	Very High
Zinc (μg g^{-1})	0.29	Very Low
Boron (μg g^{-1})	1.22	Very High

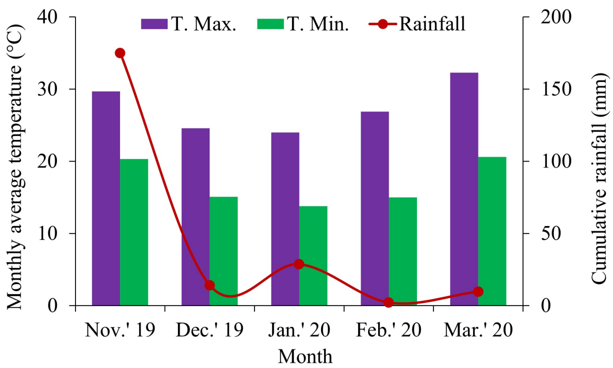

Figure 1. Temperature and rainfall pattern in the study area during the cultivation period

2.2 Experimental material

Wheat variety BARI Gom-25 was used as the experimental material is this research. This variety is semi-dwarf, early maturing and high yielding. It takes 57-61 days to heading. Spikes are long with 45-55 grains per spike. It can be grown under both optimum and late seeding conditions. Specially, suitable for growing well in southern region having salinity level of 8-10 dS m^{-1} at seedling stage. It shows moderate level of tolerance to heat stress. It is highly tolerant to Bipolaris leaf blight and resistant to leaf rust diseases. Crop duration of this variety is 102-110 days and yield are 3.6 - 5.0 t ha^{-1}.

2.3 Experimental design and treatments

The experiment was arranged in a factorial randomized complete block design and replicated thrice. The plot size of the experiment was 12 m^2 maintaining a spacing of 1.5 m and 1.0 m between the replications and the plots, respectively. The experiment consisted of three timing of N application (T1: 66% at sowing and 34% at the 3-leaf stage, T2: 50% at 3-leaf, 30% at jointing and 20% at the booting stage, T3: 50% at 6-leaf, 30% at jointing and 20% at the booting stage) and three rates of N (D1: 120 kg ha^{-1}, D2: 92 kg ha^{-1} and D3: 80 kg ha^{-1}).

2.4 Field and crop management

The field was prepared by ploughing and cross-ploughing until a fine tilth was obtained. The field was kept free from weeds, stubbles and residues from previous crops. Cowdung @ 7.0 t ha^{-1} was applied 10 days before the final land preparation. N, P, K and S were used from the sources of Urea, TSP, MoP and Gypsum. The rate of P, K, and S were 30, 60 and 15 kg ha^{-1}, respectively. The total quantity of TSP, MoP and Gypsum were applied and thoroughly mixed with the soil at the time of final land preparation. Treated seeds (BARI Gom-25; a heat and moderately saline-tolerant variety) were sown (on 27 November 2019) in a continuous line with a spacing of 20 cm between the lines. The N fertilizer (urea) was applied as per the treatments and has been sown in Table 2. The other intercultural operations such as weeding, irrigation, and plant protection measures were kept uniform in all the plots.

2.5 Sampling and data collection

Plant growth parameters were collected from the five randomly selected plants in each plot. The crops were harvested at full maturity (crop duration: 115 days). Five plants were selected randomly for the collection and measurement of yield attributes and calculation of yield. Data on plant height, tiller no. $plant^{-1}$, spike length, grains $spike^{-1}$, 1000-seed weight and harvest index were measured and calculated. The grain and straw yield were measured on a whole plot basis and then converted to t ha^{-1} at 14% moisture content.

2.6 Statistical analysis

The recorded data were accumulated and analysed using analysis of variance (two-way ANOVA) techniques with the help of the statistical package 'Statistix' 10.0. The comparison among the treatment means were tested by least significant difference (LSD) at a 95% confidence level.

3 Results and Discussion

3.1 Growth attributes

Plant height and tiller $plant^{-1}$ were varied significantly (P<0.05) with the variation of N rates but N application schedule and the interaction of application schedule with rates of N had no significant effect on both parameters (Table 2). At 75 DAE, the application of N @ 120 kg ha^{-1} resulted in the tallest plant which was statistically similar to 92 kg N ha^{-1}. Irrespective of the scheduling of the application higher rate of N increased the plant height and tillers $plant^{-1}$ which might be due to the better uptake and utilization of N as a result of the adequate supply. The results of the current study were also confirmed by Ullah et al. (2018); Erkeno and Dechass (2019), who reported also similar results that the plant height increased at a higher rate of N Ayub et al. (2001) who noticed that the highest plant height and tiller plant^{-1} were achieved with the application of N in three splits rather than two and single splits.

3.2 Yield components

Grains spike^{-1} and 1000-grain weight were differed significantly due to the variation in the scheduling of N application, rates of N application and their interaction but no significant influence on spike length and harvest index (Table 3). The maximum number of grains spike^{-1} and 1000-grains weight were attained in the application of N in three splits @ 50% at 3-leaf, 30% at jointing and 20% at the booting stages with 120 kg N ha^{-1}. Statistically, a similar result was found in the same application schedule with 92 kg N ha^{-1} and two splits (66% at sowing and 34% at the 3-leaf stage) with 120 kg N ha^{-1}. Appropriate scheduling of N and optimum rate of N application enhances the rate of photosynthesis and enhance the translocation of photosynthates to the reproductive parts resulting in higher grain spike and grain size. The results of this study are supported by Liu et al. (2019) and Sohail et al. (2018) who noted that the application of N in three splits improved the grain spike^{-1} and 1000-grain weight rather than two splits and all at basal application. The results of this experiment are in agreement with the findings of wei Tian et al. (2018) who reported that the splits application of N avoiding basal application boosted the yield attributes with a reduced rate of nitrogen supply.

3.3 Yield and total dry matter

The grain yield of wheat varied from 2.36 to 4.12 t ha^{-1} due to different scheduling of N application with various rates. Application of N in three splits @ 50% at 3-leaf, 30% at jointing and 20% at the booting stage with 120 kg N ha^{-1} significantly improved the grain yield of wheat which was statistically similar with the same application schedule with 92 kg N ha^{-1} and two splits (66% at sowing and 34% at the 3-leaf stage) with 120 kg N ha^{-1} (Fig. 2A). This improved grain yield was attributed by the higher yield attributes. Three splits of N application at 3-leaf, jointing and booting stages may meet the crop demand and enhances the N uptake and utilization which leads to better yield attributes and yield. Kharub et al. (2010) and Haile et al. (2012) noticed that proper distribution with three splits application of N improved the grain yield of wheat. The results are in conformity with the results of Tilahun Chibsa et al. (2017) and Belete et al. (2018) who reported that the right timing of N application in different splits decreased the N requirement and yield improvement of wheat. Like grain yield, a similar trend was also observed in total dry matter accumulation that the timing of N application @ 60% at 3-leaf, 30% at jointing and 20% at the booting stage with 120 kg N ha^{-1} produced the highest dry matter accumulation (Fig. 2B). This higher dry matter accumulation was statistically on similarity due to same application schedule with 92 kg N ha^{-1} and two splits (66% at sowing and 34% at the leaf-stage) with 120 kg N ha^{-1} (Fig. 2B). Zhang et al. (2021) reported similar findings that the total dry matter accumulation was improved with the appropriate amount and timing of N application in different growth stages. Gupta et al. (2020) noted that biomass accumulation significantly higher with a 50% higher rate of N.

3.4 Grain yield *vs* grains spike^{-1} and 1000-grain weight

The correlation of grain yield with grain spike was found positive and significant (Fig. 3A). The relationship between grain yield and grains spike^{-1} could be explained at 78% by the linear regression equation of $y = 0.1095x - 2.5655$. The variation of grain yield from 2.36 to 4.12 is due to the increase of the number of grain spike^{-1} from 46-59. The relationship between grain yield and 1000-grain weight was correlated positively and significantly (Fig. 2B) and the correlation could be clarified at 92% with the linear regression equation of $y = 0.0988x - 1.8315$. The increase of 1000-grain weight from 43-61 g improved the grain yield from 2.36 to 4.12 t ha^{-1}.

3.5 Economic analysis

The production cost of wheat among the treatments varied from BDT 80750 to BDT 83417. Application schedule of N @ 50% at 3-leaf, 30% at jointing and 20% at the booting stages with 92 kg N ha^{-1} significantly attained the maximum net income and higher benefit-cost ratio which was on parity with the same application schedule with 120 kg N ha^{-1} and two splits (66% at sowing and 34% at the 3-leaf stage) with 120 kg N ha^{-1} (Fig. 4). This higher net income was achieved due to the reduced rates of N with higher grain yield by efficient utilization of N.

4 Conclusion

Growth, yield traits and yield of wheat were substantially influenced by the timing and rates of N application. Application of N in three splits @ 50% at 3-leaf, 30% at jointing and 20% at the booting stages produced the higher seed yield with 120 kg N ha^{-1} but a similar yield was achieved from a 25% reduced rate of N (92 kg ha^{-1}). Timely and split application

Table 2. Application schedule of N fertilizer

Treatment	N (urea) (kg ha^{-1})	Urea (kg ha^{-1}) installment on different growth stages				
		Sowing	3-Leaf	6-Leaf	Jointing	Booting
T1D1	265	175	90	-	-	-
T2D1	265	-	132	-	80	53
T3D1	265	-	-	132	80	53
T1D2	200	130	70	-	-	-
T2D2	200	-	100	-	60	40
T3D2	200	-	-	100	60	40
T1D3	174	114	60	-	-	-
T2D3	174	-	87	-	52	35
T3D3	174	-	-	87	52	35

T1 = 66% at sowing and 34% at 3-leaf stage, T2 = 50% at 3-leaf, 30% at jointing and 20% at booting stage and T3 = 50% at 6-leaf, 30% at jointing and 20% at booting stage; D1 = 265 kg urea ha^{-1}, D2 = 200 kg urea ha^{-1}, and D3 = 174 urea kg ha^{-1}

Table 3. Interaction effect of application schedule and rates of N on growth and yield attributes of wheat grown in the coastal soil of southwestern Bangladesh

Treatment	Plant height (cm)	No. of tillers plant^{-1}	Spike length (cm)	No. of grains spike^{-1}	1000-grain weight (g)	Harvest index (%)
T1D1	95.3	3.4	14.5	56.5	60.1	49.69
T2D1	85.4	3.1	14.5	55	46.2	44.25
T3D1	88.2	2.6	14.4	42.9	43.3	46.09
T1D2	95.4	3.5	14.5	59	61.2	46.53
T2D2	93.9	3.4	14.5	59.3	56	46.39
T3D2	86.2	2.7	14.2	46.5	44.4	45.03
T1D3	84.7	3.5	14.4	51.5	48.8	46.22
T2D3	79.9	3.2	14.3	49.1	43.2	44.91
T3D3	84.3	3.2	14.3	46.4	46.8	44.18
Sig.levels						
T	ns	ns	ns	**	**	ns
D	*	*	ns	**	**	ns
T × D	ns	ns	ns	**	**	ns

T1 = 66% at sowing and 34% at 3-leaf stage, T2 = 50% at 3-leaf, 30% at jointing and 20% at booting stage and T3 = 50% at 6-leaf, 30% at jointing and 20% at booting stage; D1 = 265 kg urea ha^{-1}, D2 = 200 kg urea ha^{-1}, and D3 = 174 urea kg ha^{-1}

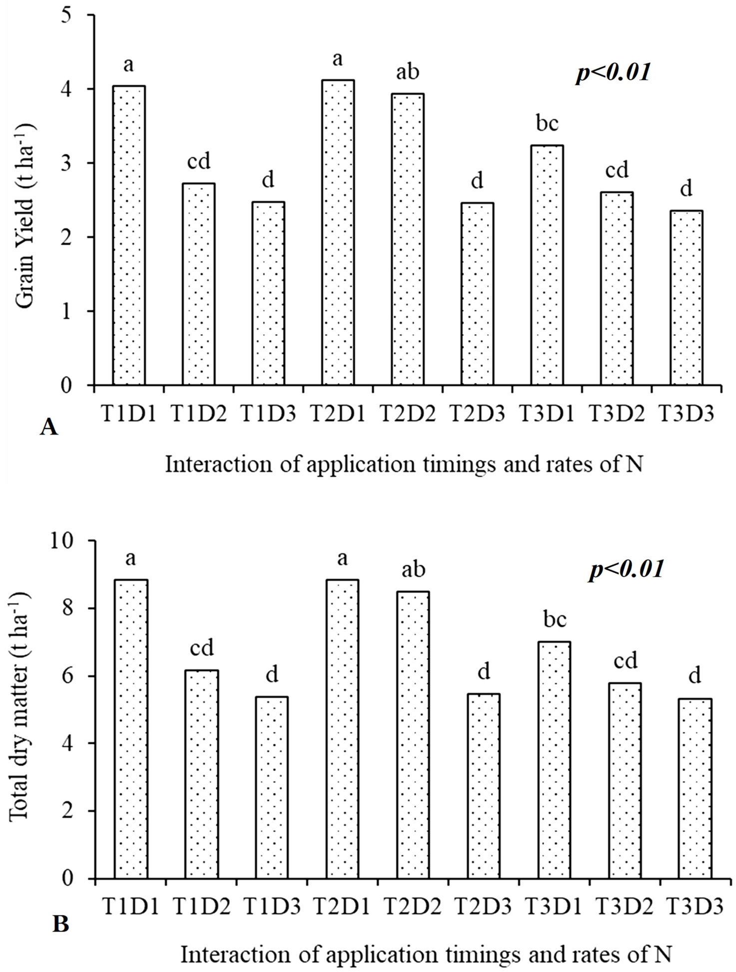

Figure 2. Interaction effect of application schedule and rates of N on grain yield (A), and total dry matter (B) accumulation of wheat grown in the coastal soil of southwestern Bangladesh. Here, T1 = 66% at sowing and 34% at 3-leaf stage, T2 = 50% at 3-leaf, 30% at jointing and 20% at booting stage and T3 = 50% at 6-leaf, 30% at jointing and 20% at booting stage; D1 = 120 kg N ha^{-1}, D2 = 92 kg N ha^{-1}, and D3 = 80 N kg ha^{-1}

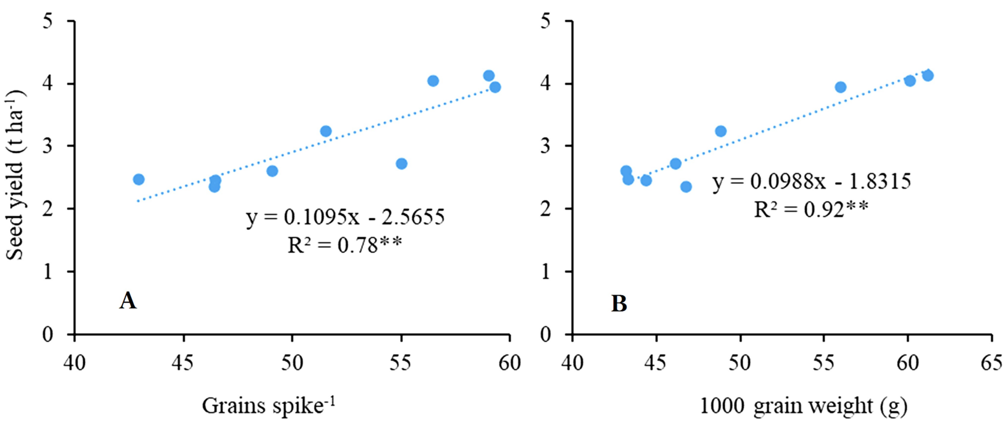

Figure 3. Relationship between grain yield with grain spike^{-1} (A), and 1000-grain weight (B) of wheat

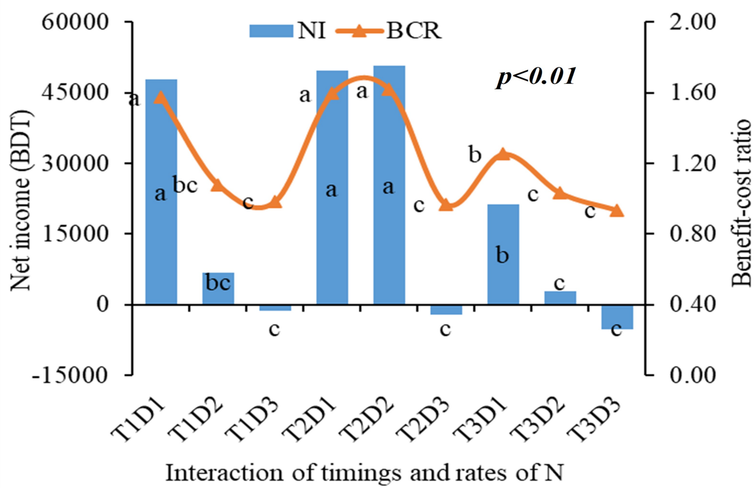

Figure 4. Interaction effect of application schedule and rates of N on net income and benefit-cost ratio of wheat grown in the coastal soil of southwestern Bangladesh

of nitrogen allowed for more efficient use of nitrogen throughout the growing season as it provided desired amounts of nitrogen according to the crop demand on critical growth stages might reduce the loss and improve the efficiency of N. From the findings of this study, we may conclude that N @ 92 kg ha^{-1} applied in three splits @ 50% at 3-leaf, 30% at jointing and 20% at the booting stage could be the suitable management approach for wheat in the coastal region of southwestern Bangladesh.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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