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Title: Nitrogen Rationing and Scheduling to Improve Yield of Wheat in Nitrogen Deficit Soil of Southwest Bangladesh

Authors: Mahbuba Yesmeen Chaity, Md. Yasin Ali* and Md. Sarwar Jahan

Agrotechnology Discipline, Khulna University, Khulna-9208, Bangladesh

Corresponding Author: Md. Yasin Ali Email: drmdyasinali@at.ku.ac.bd

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ABSTRACT

Nitrogen (N) is an important macro nutrient element for crops and its availability to plants largely vary on soil properties and overall soil environment such as soil temperature, soil moisture, microbial population etc. Its available forms $NO3^-$ and $NH4^+$ both are very much mobile in plants and $NO3^-$ is mobile in soils but ammonium ($NH4^+$) has a low mobility in soil due to its positive charge, which attracts it to negatively charged soil particles and organic matter. So, N recommendation should be not only crop spacific but also soil spacific and season spacific. Keeping this fact in mind, an experiment was conducted at the Dr. Purnendu Gain Field Laboratory of Agrotechnology Discipline, Khulna University, Khulna during November 2016 to March 2017 to optimize rationing and scheduling of nitrogen for wheat in a N deficit coastal soil. Growth and yield parameters of BARI Gom-25, a salt tolerent variety, was assessed. The experiment was laid out in randomized complete block design (RCBD) with four N levels i.e. D0 = 0 kg ha^{-1}, D1 =50 kg ha^{-1} (50% less), D2 =100 kg ha^{-1} (recommenrded), and D3 = 150 kg ha^{-1} (50% more) in factorial combination with three N application time (T1= 66:34:0, T2= 34:33:33, T3= 0:50:50 applied at basal, crown root initiation (CRI) stage (25DAS) and jointing stage (45DAS), respectively) as treatments with three replications. Experimental data on dry matter partitioning (leaves, stem, flag leaf and spike dry weight plant^{-1} at different days after sowing), crop phenology, yield and yield attribute were collected and analyzed statistically. The results revealed that the different rate and time of N application had significant effect on all the parameters of the experiment. Nitrogen at 150 kg ha^{-1} (D3) with 2 splits application (T1) contributed to highest dry matter accumulation in leaves at 60 DAS (5.19 g), in stem at 70 DAS (11.47 g) and in flag leaf at 80 DAS (2.30 g) then these were decreased up to harvest. Spike dry weight was increased gradually and reached the peak at the time of harvest (3.86 g) at 100 kg N ha^{-1} with 2 splits (T1). Days to flowering and days to maturity were delayed due to application of extra N (D3). Growth parameters were found to be higher at 150 kg N ha^{-1} with 2 splits application (D3T1). All the yield and yield contributing characters of the crop except unfilled grain spike^{-1} and straw yield were found superior with 100 kg ha^{-1} (D2) of N application in two splits (T1) that contributed to obtain the highest grain yield (4.27 t ha^{-1}). The highest straw yield (5.67 t ha^{-1}) was obtained from D3T1 treatment combination. Higher agronomic N use efficiency (35 kg kg^{-1}) was observed in D1T1followed by D2T1(32.7 kg kg^{-1}) and the highest relative economic return (102659 Tk.) was in D2T1 followed by D2T2 (94926 Tk.) treatment combinations. Thus, 100 kg N with 2 splits (T1 = 66:34:0) application at basal and CRI stage (25DAS) could be the optimum N application schedule for wheat in N deficit soil of southwest Bangladesh.

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INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most important crop and counted among the 'big three' cereal crops both in area and production and known as king of cereals (Costa et al., 2013). According to the United States Department of Agriculture (USDA) estimation, world wheat production in 2016-2017 was 751.36 million metric tons (mt.). Production in the year 2020 - 21 was 772 million mt (USDA, 2017). It is the staple food for about one billion in as many as 43 countries and it contains carbohydrate (78.1%), protein (14.7%), minerals (2.1%), fat (2.1%) and considerable proportion of vitamins (Jahan, 2014). Wheat is cool-loving crop and adopted for cultivation in regions with cooler climatic conditions. In Bangladesh, wheat is grown in the winter season from November to April. Mean temperature during wheat growing period ranges from 18.8 ^{0}C to 25.3 ^{0}C. Although wheat is cultivated in a large area (0.45 million ha) in Bangladesh but the average yield of wheat is very low (3.03 t ha^{-1}). The low yield of wheat may be due to various reasons such as lack of suitable varieties, quality seed, untimely sowing, imbalanced fertilization, seed rate, sowing techniques etc. Balanced fertilization and better cultural practices are important for obtaining higher yield of wheat.

Optimal crop growth requires a continuous supply of water, nutrients and radiation (Gregory, 1986). Among plant nutrients nitrogen has been considered as a major growth and development element (Nikolic et al., 2012). Optimum availability of N to wheat plant results in promising plant growth (Ahmad et al., 2012) and higher yield (Iqbal et al., 2010; Ali et al., 2012) compared to improperly fertilized plants. The response to N fertilization varies according to location, climate, crops and their varieties, type and characteristics of the soil, rate and time of fertilizer application and its placement. Unlike the other major plant nutrient elements, nitrogen is the most limiting one in most of the soils of Bangladesh for sustenance of optimum plant growth. Therefore, this nutrient is mostly added extraneously in order to supplement their deficiencies in soil for successful crop production.

It is well established that N influences various plant parameters. For example, Waraich et al., (2002) observed that increased nitrogen results in maximum leaf area index at tillering and booting stages, number of tillers, net assimilation rate, relative growth rate, grain weight and grain yield. Nitrogen is responsible for shoot and root growth (Comfort et al., 1988) grain formation (Arduini et al., 2006) and protein synthesis (Acreche et al., 2009). Nitrogen stress restricted growth of wheat plants and their dry matter production (Arduini et al., 2006). High nitrogen treatment increased the number of tillers and shoot dry matter (Laghari et al., 2010). However, Latiri et al. (1998) reported that nitrogen stimulated dry matter production substantially due to increased leaf area index, which resulted in improved efficiencies of radiation and water use. Kubar et al. (2022) stated that 225 kg N ha^{-1} significantly enhanced the stomatal conductance (G_s), photosynthetic rate (P_n), intercellular CO_2 (C_i), transpiration rate (T_r), and total chlorophyll by 28.5%, 42.3%, 10.0%, 15.2%, and 50%, receptively, at the jointing stage in comparison to the control (0 kg N ha^{-1}). Nitrogen application of 225 kg ha^{-1} increased the soil–plant analysis development (SPAD) value and the chlorophyll a, chlorophyll b, and carotenoid contents of winter wheat under the 6:4:0:0 ratio. The trend of the photosynthetic characteristics was observed to be greater at the 6:4:0:0 fertilization ratio compared to that at 5:5:0:0.

Nitrogen is usually applied at sowing. Such applied N is subjected to various losses, particularly early in the season when crop uptake is low. It is, therefore, important to devise fertilizer application strategies that can improve N uptake and hence grain yield of wheat. It is established that split application of nitrogen is better than single application for increasing yield of wheat (Gravelle et al., 1989). Top dressing and split application of nitrogen fertilizers at critical crop growth stages of wheat are now emphasized (Singh, 1989). However, the yield response varies with number of split and time of nitrogen application. Besides this, the quality of wheat is directly related to protein content. High grain protein level in wheat is an important consideration for human nutrition but the varieties grown in Bangladesh are of low to medium protein content (Warsthorn, 1988). High grain quality required a steady nutrient supply. Many authors have found that most of the nitrogen uptaken by wheat plants occurs before anthesis (Frank et al., 1989).

Hence, it would be a good effort to develop an effective schedule for nitrogen management for wheat crop by the way of quantity, split and time of application.

Thus the present research was conducted to evaluate the effect of different rate and time of nitrogen application on dry matter partitioning and yield in wheat. Keeping all these in view, the present study was undertaken to observe the effect of rate and schedule of nitrogen application on growth, dry matter partitioning and yield of wheat and to determine the optimum rate and schedule of nitrogen application for wheat in N deficit soil of southwest Bangladesh.

MATERIALS AND METHODS

The experiment was conducted during November, 2016 to March, 2017. The experiment was conducted at the Dr. Purnendu Gain Field Laboratory of Agrotechnology Discipline, Khulna University, Khulna under the Agro ecological Zone (AEZ) 13 (Gangetic Tidal Floodplain). The experimental soil was clay loam with slightly acidic (pH 5.8) and salinity (5.74 dS m^{-1}), moderate organic matter content (2.03%) and low nitrogen (0.18%) and phosphorus (7.08 ppm) content.

BARI Gom-25 was used as planting material in the experiment. This variety is suitable for growing well in southern region having salinity tolerance level of 8-10 dS/m at seedling stage. It is highly tolerant to *Bipolaris* leaf blight and resistant to leaf rust diseases (BARI, 2019).

Experimental treatment

The experiment consisted of two factors: Factor A: Rate of nitrogen application: 4 doses (kg ha^{-1}) -

D_0 = 0, D_1 =50 (50% of recommended rate), D_2 =100 (Recommended rate), D_3 = 150 (150% of recommended rate) and Factor B: Time of nitrogen application: applied 3 times at basal, CRI stage (25 DAS) and jointing stage (45 DAS) at a ratio of T1= 66:34:0, T2= 34:33:33, T3= 0:50:50, respectively.

Fertilizer application

Fertilizers like TSP, MoP and gypsum and compost were applied to the experimental field as basal dose at the rate of 29.57 kg, 24.90 kg and 19.80 kg P, K and S per hectare, respectively. Additionally, compost at the rate of 10 ton per hectare was applied to the experimental field 7 days before seed sowing. Nitrogen fertilizer in the form of urea was applied as per treatment description.

Experimental design

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The size of the unit plot was 4 m^2 (2 m × 2 m).

Seeds were treated with Vitavex-200 @ 3 g kg^{-1} of seed before sowing to prevent seeds from the attack of soil borne diseases. Seeds were sown continuously in line on 8 December, 2016 at the rate of 120 kg ha^{-1} at 4-5 cm depth. The distance was maintained 20 cm. Intercultural operations were done as and when necessary to ensure normal growth of the crop. The crop was harvested at full maturity stage in different dates on the basis of maturity due to different rates and times of nitrogen fertilizer application. Harvesting was ended at 18 March, 2017 (at 98 DAS).

Data collection

Crop growth characters such as plant height at different days after sowing, number of tiller/plant at different days after sowing, dry weight of different plant parts at 10 days interval starting from 30 DAS, days to heading, days to maturity and yield and yield contributing characters such as number of effective tiller/plant, spike length, number of grain/spike, number of unfilled grain /spike, 1000 grain weight, grain yield, straw yield, harvest index (HI) were collected.

RESULTS AND DISCUSSION

Interaction effect of different rates and times of nitrogen application on crop growth and dry matter partitioning

Plant height

Statistically significant ($p<0.01$) variation was found regarding plant height of wheat at different growth stages due to the interaction effects of different rate and time of nitrogen application (Table 1). Data showed that plant height increased with the advancement of crop growth and the highest height was recorded at harvest. Higher doses of nitrogen enhanced longer plants. Split application of nitrogen showed significant impact on plant height. The highest plant height at all the growth stages was observed with 150 kg N ha^{-1} (D3) applied in two splits 2/3rd at final land preparation and 1/3rd at the time of first irrigation (25 DAS) (T1). At harvest the longest plant (103.20 cm) was recorded from D_3T_1 and the shortest plant (63.67 cm) was recorded from D_0T_3 treatment combinations (Table 1). Nitrogen contributes in cell elongation of plants; hence higher nitrogen rate (150 kg Nha^{-1}) applied in proper time (T1) resulted the longest plant height. Similar result was attained by Nazir et al. (2000) who observed the longest plant in wheat with 150 kg Nha^{-1}.

Table 1. Interaction effect of different rates and times of nitrogen application on plant height of wheat at different days after sowing

Interaction		**Plant height (cm)**				
Treatment A	Treatment B	30 DAS	45 DAS	60 DAS	75 DAS	At harvest
D_0	T_1	22.2 f	33.67 g	49.00 h	63.83 h	66.17 h
	T_2	19.3 h	31.67 h	48.00 h	63.00 i	64.67 i
	T_3	20.0 g	30.67 i	44.33 i	60.67 j	63.67 j
D_1	T_1	29.8 a	44.90 f	67.37 e	79.87 f	81.68 f
	T_2	27.3 c	44.83 f	65.97 f	79.00 f	81.80 f
	T_3	24.9 e	44.20 f	63.67 g	76.27 g	77.87 g
D_2	T_1	28.6 b	50.00 c	70.17 d	88.90 d	87.07 d
	T_2	25.9 d	48.33 d	67.17 ef	85.00 e	83.23 e
	T_3	26.7 c	46.90 e	67.23 ef	84.97 e	82.33 e
D_3	T_1	29.3 a	56.50 a	89.00 a	100.7 a	103.2 a
	T_2	29.5 a	56.27 a	87.50 b	99.27 b	101.2 b
	T_3	27.4 c	54.07 b	83.67 c	95.50 c	97.93 c
CV (%)		3.71	2.85	2.82	2.21	2.56
SE		0.64	0.85	1.25	0.74	1.37
Significance level		**	**	**	**	**

Mean values within the column with similar letter are not significantly ($p<0.01$) different.

D_0 = 0 kg N ha^{-1} (Control), D_1 = 50 kg N ha^{-1}, D_2 = 100 kg N ha^{-1} and D_3= 150 kg N ha^{-1}

T_1: 2/3rd portion of nitrogen was applied at final land preparation+1/3rd portion of nitrogen was applied at the time of first irrigation (25 DAS)

T_2: 1/3rd portion of nitrogen was applied at final land preparation+1/3rd portion of nitrogen was applied at the time of first irrigation (25 DAS) +1/3rd portion of nitrogen was used at the time of second irrigation (45 DAS)

T_3:1/2 portion of nitrogen was applied at the time of first irrigation (25 DAS) +1/2 portion was applied at second irrigation (45 DAS)

DAS = Days after sowing, CV= Co-efficient of Variation, ****** = Significant at 1% level of significance

Tiller number

Tiller number plant^{-1} was statistically significant (p<0.01, 0.05) due to the interaction effect of different rates and times of nitrogen application on wheat at all growth stages (30 DAS, 45 DAS, 60 DAS and at maturity) (Table 2). Tiller number plant^{-1} showed similar trend as plant height. Tiller number increased progressively and it was the highest at harvest which had no significant different from that of 60 DAS. Higher number of tillers produced with 150 kg N ha^{-1} (D_3) applied in two splits 2/3rd at final land preparation and 1/3rd at the time of first irrigation (25 DAS) (T_1). At harvest, the highest tiller number plant^{-1} (9.00) was obtained from D_3T_1 which was statistically similar to D_2T_1 (8.67) and the lowest tiller number plant^{-1} (1.00) was obtained from T2 and T3 without nitrogen. Results indicate that, 100 or 150 kg ha^{-1} N application showed better performance in tiller production and the best result was observed when N was applied 2/3rd of total N at final land preparation and 1/3rd of that at the time of first irrigation (T_1) followed by T_2. The variation in number of tillers may be due to higher dose of nitrogen and availability for longer period due to split application and also due to earlier availability in case of basal application. These results are in conformity with the findings of Nazir et al. (2000).

Table 2. Interaction effect of different rates and times of nitrogen application on tiller number plant^{-1} of wheat at different days after sowing

Interaction		**Tiller number plant $^{-1}$**			
Treatment A	Treatment B	30 DAS	45 DAS	60 DAS	At harvest
D_0	T_1	0.33 g	1.00 i	1.00 i	1.03 i
	T_2	0.34 g	1.05 i	1.20 i	1.00 i
	T_3	0.31 g	1.00 i	1.00 i	1.00 i
D_1	T_1	2.00 e	4.00 e	4.00 de	4.00 de
	T_2	1.33 f	2.67 g	3.67 e	3.67 e
	T_3	2.33 d	2.33 h	2.33 f	2.33 f
D_2	T_1	3.33 b	6.33 a	8.33 a	8.67 a
	T_2	2.00 e	4.33 d	6.33 b	7.33 b
	T_3	2.33 d	3.67 f	4.33 cd	4.33 d
D_3	T_1	3.67 a	5.67 b	8.67 a	9.00 a
	T_2	2.67 c	5.00 c	6.67 b	7.33 b
	T_3	2.33 d	4.33 d	4.67 c	5.00 c
CV (%)		28.65	18.25	14.04	17.59
LSD		0.26	0.30	0.40	0.52
SE		0.12	0.19	0.40	0.33
Significance level		*	*	**	**

Mean values within the column with similar letter are not significantly (p<0.01) different.
D_0 = 0 kg N ha^{-1} (Control), D_1 = 50 kg N ha^{-1}, D_2 = 100 kg N ha^{-1} and D_3= 150 kg N ha^{-1}
T_1: 2/3rd portion of nitrogen was applied at final land preparation+1/3rd portion of nitrogen was applied at the time of first irrigation (25 DAS)
T_2: 1/3rd portion of nitrogen was applied at final land preparation+1/3rd portion of nitrogen was applied at the time of first irrigation (25 DAS) +1/3rd portion of nitrogen was used at the time of second irrigation (45 DAS)
T_3:1/2 portion of nitrogen was applied at the time of first irrigation (25 DAS) +1/2 portion was applied at second irrigation (45 DAS)
DAS = Days after sowing, CV= Co-efficient of Variation, LSD= Least Significant Difference, ***** = Significant at 5% level of significance, ****** = Significant at 1% level of significance

Leaf dry weight

The interaction effects of rates and times of nitrogen application was found significant (p<0.01, 0.05) for leaf dry weight of wheat at different growth stages (30 DAS, 40 DAS, 50 DAS, 60 DAS, 70 DAS, 80 DAS and at harvest) (Table 3 and Figure 1). All growth stages showed similar pattern in leaf dry matter accumulation. The highest values were observed at 60 DAS and decreased thereafter. The decrease in leaf dry matter after 60 DAS may be due to decrease in leaf number and translocation of reserved food from leaf to spike during reproductive stage; which is also supported by Khan et al. (2014). The highest leaf dry weight was observed from 150 kg N ha^{-1} (D_3) applied 2/3rd at final land preparation and 1/3rd at the time of first irrigation (25 DAS) (T_1) followed by1/3rd portion applied at final land preparation, 1/3rd N applied at the time of first irrigation (25 DAS) and 1/3rd at the time of second irrigation (45 DAS) (T2). Lowest leaf dry matter was recorded from all the treatment combinations without nitrogen. Similar result was attained by Nazir et al. (2000).

Table 3. Interaction effect of different rates and times of nitrogen application on leaf dry weight of wheat at different days after sowing

Interaction		Dry weight of leaves (g)						
Treatment A	Treatment B	30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80DAS	At harvest
D_0	T_1	0.15 i	0.23 g	0.27 j	0.43i	0.40 i	0.38 i	0.35 i
	T_2	o.13 j	0.20 gh	0.26 j	0.39i	0.39 i	0.35 i	0.33 i
	T_3	0.10 k	0.15 h	0.24 j	0.33i	0.31 i	0.30 i	0.28 i
D_1	T_1	0.39 f	0.58 e	1.57 f	3.01 f	2.88 f	2.70 f	2.52 f
	T_2	0.30 h	0.45 f	1.37 h	2.67 g	2.51 g	2.40 g	2.23 g
	T_3	0.31 h	0.46 f	1.00 i	1.96 h	1.81 h	1.76 h	1.64 h
D_2	T_1	0.58 b	0.88 b	2.16 c	4.21 c	3.97 c	3.79 c	3.53 c
	T_2	0.52 d	0.79 c	1.92 d	3.74 d	3.54 d	3.37 d	3.13 d
	T_3	0.35 g	0.62 e	1.49 g	2.91 e	2.70 fg	2.62 f	2.44 f
D_3	T_1	0.65 a	0.98 a	2.66 a	5.19 a	4.83 a	4.67 a	4.33 a
	T_2	0.55 c	0.83 c	2.31 b	4.51 b	4.17 b	4.06 b	3.78 b
	T_3	0.46 e	0.70 d	1.75 e	3.42 e	3.20 e	3.08 e	2.87 e
CV (%)		12.33	16.35	10.87	11.10	11.14	11.15	11.16
SE		0.02	0.05	0.08	0.20	0.19	0.18	0.17
Significance level		*	*	*	**	**	**	**

Mean values within the column with similar letter are not significantly ($p<0.01$) different; D_0 = 0 kg N ha^{-1} (Control), D_1 = 50 kg N ha^{-1}, D_2 = 100 kg N ha^{-1} and D_3= 150 kg N ha^{-1}

T_1: 2/3rd portion of nitrogen was applied at final land preparation+1/3rd portion of nitrogen was applied at the time of first irrigation (25 DAS)

T_2: 1/3rd portion of nitrogen was applied at final land preparation+1/3rd portion of nitrogen was applied at the time of first irrigation (25 DAS) +1/3rd portion of nitrogen was used at the time of second irrigation (45 DAS)

T_3:1/2 portion of nitrogen was applied at the time of first irrigation (25 DAS) +1/2 portion was applied at second irrigation (45 DAS)

DAS = Days after sowing, CV= Co-efficient of Variation, ***** = Significant at 5% level of significance, ****** = Significant at 1% level of significance

Stem dry weight

The data revealed that statistically significant ($p<0.01$, 0.05) variation was found for dry weight of stem of wheat at different dates of sowing (30 DAS, 40 DAS, 50 DAS, 60 DAS, 70 DAS, 80 DAS and at harvest) due to the interaction effect of different rates and times of N application (Table 4 and Figure 1). During tillering stage (30 DAS), the maximum stem dry weight (1.09 g) was obtained from D_3T_1 and the minimum stem dry weight (0.17 g) was obtained from D_0T_3. At the time of stem elongation (40 DAS), the highest stem dry weight (5.66 g) was obtained from D_3T_1 and the lowest stem dry weight (0.39 g) was obtained from D_0T_3. After the flag leaf emergence (50 DAS), the highest stem dry weight (7.55 g) was obtained from D_3T_1 and the lowest stem dry weight (0.52 g) was obtained from D_0T_3 which was statistically similar to that of D_0T_1 (0.66 g) and D_0T_2 (0.64 g). At the time of spike initiation (60 DAS), the highest stem dry weight (9.72 g) was obtained from D_3T_1

and the lowest stem dry weight (0.71 g) was obtained from D_0T_3 which was statistically similar to that of D_0T_1 (0.87 g) and D_0T_2 (0.85 g). At 70 DAS, the highest stem dry weight (11.47 g) was obtained from D_3T_1 and the lowest stem dry weight (0.77 g) was obtained from D_0T_3 which was statistically similar to that of D_0T_1 (1.02 g) and D_0T_2 (0.99 g). During ripening stage , the highest stem dry weight (11.35 g) was obtained from D_3T_1 and the lowest stem dry weight (0.73 g) was obtained from D_0T_3 which was statistically similar to that of D_0T_1 (0.92 g) and D_0T_2 (0.85 g). Finally at harvest, the highest stem dry weight (10.21 g) was obtained from D_3T_1 and the lowest stem dry weight (0.69 g) was obtained from D_0T_3 which was statistically similar to D_0T_1 (0.89 g) and D_0T_2 (0.80 g). Interaction of varied nitrogen rates and application time had significant effect on dry weight of stem. The variation in dry weight of stem may be due to the increased availability with higher dose of N in earlier stage due to higher basal dose. These results are in conformity with the findings of Nazir et al. (2000) who stated that, the highest dry weight of stem recorded with the application of 150 kg N ha^{-1} into 2 splits (T_1).

Table 4. Interaction effect of different rates and times of nitrogen application on stem dry weight of wheat at different days after sowing

Interaction		**Stem dry weight (g)**						
Treatment A	Treatment B	30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80DAS	At harvest
D_0	T_1	0.26 i	0.50 g	0.66 g	0.87 i	1.02 j	0.92i	0.89 i
	T_2	0.22 j	0.48 g	0.64 g	0.85 i	0.99 j	0.85i	0.80 i
	T_3	0.17 k	0.39 g	0.52 g	0.71 i	0.77 j	0.73i	0.69 i
D_1	T_1	0.65 f	3.75 d	5.01 d	6.28 e	7.09 f	6.57 f	6.50 e
	T_2	0.50 h	3.33 e	4.43 e	5.23 g	5.96 h	5.83 g	5.82 g
	T_3	0.51 h	2.26 f	3.01 f	3.88 h	4.41 i	4.27 h	4.07 h
D_2	T_1	0.97 b	4.87 b	6.49 b	8.43 b	9.44 c	9.21 c	8.85 b
	T_2	0.87 d	4.34 c	5.78 c	7.33 c	8.39 d	8.18 d	7.70 c
	T_3	0.58 g	3.44 e	4.58 e	5.64 f	6.55 g	6.35 f	5.93 f
D_3	T_1	1.09 a	5.66 a	7.55 a	9.72 a	11.47 a	11.35 a	10.21 a
	T_2	0.92 c	5.07 b	6.76 b	8.20 b	10.04 b	9.85 b	8.62 b
	T_3	0.78 e	3.75 d	5.00 d	6.65 d	7.67 e	7.48 e	6.98 d
CV (%)		12.33	11.29	11.29	12.92	11.39	11.15	12.92
SE		0.04	0.24	0.32	0.33	0.34	0.44	0.35
Significance level		*	**	**	*	*	**	*

Mean values within the column with similar letter are not significantly ($p<0.01$) different; D_0 = 0 kg N ha^{-1} (Control), D_1 = 50 kg N ha^{-1}, D_2 = 100 kg N ha^{-1} and D_3= 150 kg N ha^{-1}

T_1: 2/3rd portion of nitrogen was applied at final land preparation+1/3rd portion of nitrogen was applied at the time of first irrigation (25 DAS)

T_2: 1/3rd portion of nitrogen was applied at final land preparation+1/3rd portion of nitrogen was applied at the time of first irrigation (25 DAS) +1/3rd portion of nitrogen was used at the time of second irrigation (45 DAS)

T_3:1/2 portion of nitrogen was applied at the time of first irrigation (25 DAS) +1/2 portion was applied at second irrigation (45 DAS)

DAS = Days after sowing, CV= Co-efficient of Variation, ***** = Significant at 5% level of significance, ****** = Significant at 1% level of significance

Flag leaf dry weight

Results (Table 5 and Figure 1) revealed that the dry weight of flag leaf of wheat was significantly ($p<0.01$) affected by the interaction effect of different rates and times of nitrogen application at different days after sowing (50 DAS, 60 DAS, 70 DAS, 80 DAS and at harvest). After the flag leaf emergence (50 DAS), the highest flag leaf dry weight (0.44 g) was obtained from D_2T_1 which was statistically similar to that of D_3T_3 (0.43 g), D_3T_2 (0.39 g) and D_2T_2 (0.38 g) whereas the lowest flag leaf dry weight (0.03 g) was obtained from D_0T_2 which was statically similar to that of D_0T_1 (0.05 g) and D_0T_3 (0.05 g). At the time of spike initiation (60 DAS), the highest flag leaf dry weight (0.91 g) was obtained from D_3T_1 which was statically similar to that of D_3T_3 (0.90 g) and the lowest flag leaf dry weight (0.05 g) was obtained from D_0T_2 which was statically similar to that of D_0T_1 (0.08 g) and D_0T_3 (0.08 g). The highest flag leaf dry weight (1.76 g) was obtained from D_3T_1, whereas the lowest flag leaf dry weight (0.11 g) was obtained from D_0T_3 during flowering stage (70 DAS). At 80 DAS, the highest flag leaf dry weight (2.30 g) was obtained from both D_3T_3 which was statistically similar to that of D_3T_1 (2.20 g) whereas the lowest flag leaf dry weight (0.25 g) was obtained from D_0T_3. At harvest, the highest flag leaf dry weight (2.10 g) was obtained from D_3T_1 and D_3T_3 whereas the lowest flag leaf dry weight (0.20 g) was obtained from D_0T_3. This variation in dry weight of flag leaves may be due to the increased availability with higher dose of N and availability for longer period due to split application.

Table 5. Interaction effect of different rate and time of nitrogen application on dry weight flag leaf at different days after sowing

Interaction		**Dry weight of flag leaf (g)**				
Treatment A	Treatment B	50 DAS	60 DAS	70 DAS	80 DAS	At harvest
D_0	T_1	0.05 e	0.08 g	0.21 j	0.39 f	0.31 e
	T_2	0.03 e	0.05 g	0.29 i	0.37 f	0.36 e
	T_3	0.05 e	0.08 g	0.11 k	0.25 g	0.20 f
D_1	T_1	0.23 d	0.49 e	1.20 d	1.77 c	1.80 b
	T_2	0.22 d	0.48 e	1.07 f	1.76 c	1.50 c
	T_3	0.16 d	0.35 f	0.75 h	1.32 e	1.07 d
D_2	T_1	0.44 a	0.76 b	1.51 c	1.90 b	1.80 b
	T_2	0.38 ab	0.54 d	0.80 h	1.72 c	1.00 d
	T_3	0.30 c	0.54 d	1.13 e	1.77 c	1.50 c
D_3	T_1	0.36 bc	0.91 a	1.76 a	2.20 a	2.10 a
	T_2	0.39 ab	0.59 c	0.90 g	1.59 d	1.47 c
	T_3	0.43 ab	0.90 a	1.71 b	2.30 a	2.10 a
CV (%)		40.71	9.60	7.90	10.82	8.12
SE		0.07	0.03	0.05	0.10	0.07
Significance level		**	**	**	**	**

Mean values within the column with similar letter are not significantly ($p<0.01$) different; D_0 = 0 kg N ha^{-1} (Control), D_1 = 50 kg N ha^{-1}, D_2 = 100 kg N ha^{-1} and D_3= 150 kg N ha^{-1}

T_1: 2/3rd portion of nitrogen was applied at final land preparation+1/3rd portion of nitrogen was applied at the time of first irrigation (25 DAS)

T_2: 1/3rd portion of nitrogen was applied at final land preparation+1/3rd portion of nitrogen was applied at the time of first irrigation (25 DAS) +1/3rd portion of nitrogen was used at the time of second irrigation (45 DAS)

T_3:1/2 portion of nitrogen was applied at the time of first irrigation (25 DAS) +1/2 portion was applied at second irrigation (45 DAS)

DAS = Days after sowing, CV= Co-efficient of Variation, LSD= Least Significant Difference, ****** = Significant at 1% level of significance

Spike dry weight

Variation in spike dry weight of wheat variety was significant ($p<0.01$) by the interaction effect of different rate and time of nitrogen application at different dates after sowing (60 DAS, 70 DAS, 80 DAS and at harvest) (Table 6 and Figure 1). At all the growth stages, the highest spike dry weight was noticed from D_2T_1 and the lowest values were from D_0T_3. At harvest, the value of spike dry weight in D_2T_1 treatment interaction was 3.86 g and that of in D_0T_3 treatment interaction was 0.36 g. These results are in conformity with the findings of Nazir et al. (2000).

Table 6. Interaction effect of different rate and time of nitrogen application on dry weight of spike at different days after sowing

Interaction		Dry weight of spike (g)			
Treatment A	Treatment B	60 DAS	70 DAS	80 DAS	At harvest
D_0	T_1	0.37 i	0.42 j	0.50 i	0.55 j
	T_2	0.33 j	0.36 k	0.40 j	0.46 k
	T_3	0.22 k	0.28 l	0.33 k	0.36 l
D_1	T_1	0.68 g	1.51 e	2.11 d	2.70 d
	T_2	0.55 h	1.06 h	1.69 f	2.08 f
	T_3	0.39 i	0.75 i	1.26 h	1.60 i
D_2	T_1	1.53 a	2.30 a	3.27 a	3.86 a
	T_2	1.36 b	1.75 c	2.32 c	3.09 c
	T_3	1.07 e	1.35 f	1.75 e	1.92 g
D_3	T_1	1.17 c	2.19 b	2.81 b	3.18 b
	T_2	1.11 d	1.60 d	2.07 d	2.38 e
	T_3	0.86 f	1.18 g	1.61 g	1.85 h
CV (%)		6.44	4.11	4.95	3.64
SE		0.03	0.03	0.06	0.05
Significance level		**	**	**	**

Mean values within the column with similar letter are not significantly ($p<0.01$) different; Where, D_0 = 0 kg N ha^{-1} (Control), D_1 = 50 kg N ha^{-1}, D_2 = 100 kg N ha^{-1} and D_3= 150 kg N ha^{-1}

T_1: 2/3rd portion of nitrogen was applied at final land preparation+1/3rd portion of nitrogen was applied at the time of first irrigation (25 DAS)

T_2: 1/3rd portion of nitrogen was applied at final land preparation+1/3rd portion of nitrogen was applied at the time of first irrigation (25 DAS) +1/3rd portion of nitrogen was used at the time of second irrigation (45 DAS)

T_3:1/2 portion of nitrogen was applied at the time of first irrigation (25 DAS) +1/2 portion was applied at second irrigation (45 DAS)

DAS = Days after sowing, CV= Co-efficient of Variation, LSD= Least Significant Difference, ** = Significant at 1% level of significance)

Days to heading

Variation in days to heading was significant at 1% level of significance (Table 7) by the interaction effect of rates and times of nitrogen application in wheat. The maximum days to heading (60.33 DAS) were obtained from D_3T_1 and the minimum days to heading (46.67 DAS) were obtained from D_0T_3 compared to the other treatments. It might be due to excessive N application resulted in delayed heading, because excessive N kept vegetative growth active and finally resulted in delayed heading and flowering (Osman et al., 1981). Split application of N, increased N uptake more (than that of blanket application), when the first dose was applied at sowing and second dose was applied at tillering. On the other hand, delayed applications resulted in a relatively lower uptake of N even with supplementary irrigation (Adjetey et al., 2001) might due to required N was less in soil than the plant demand.

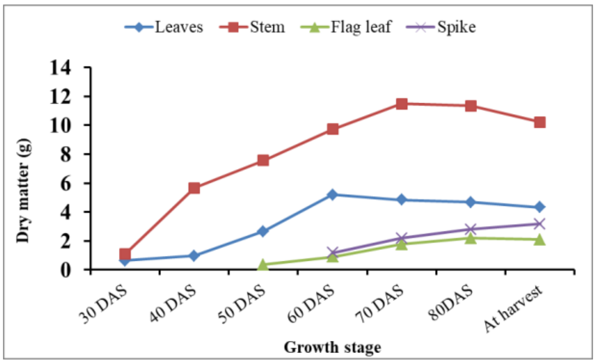

Figure 1. Dry matter accumulation pattern in different plant parts at different growth stages of wheat with 150 kg N applied at 2 splits (D_3T_1)

Days to maturity

Data regarding days to maturity was significant at 5% level of significance (Table 7) by the interaction effect of different rates and times of N application on wheat. The maximum days to maturity (98.33 DAS) were obtained from D_3T_1 and the minimum days to maturity (70.33 DAS) were obtained from D_0T_3 compared to the other treatments. Higher dose of N promotes vegetative growth and delays reproductive stage, hence days to maturity was longer in D3 (150 kg N ha^{-1}) compared to lower doses. Almost similar findings were obtained by other authors, i.e., availability of N kept vegetative growth active and finally resulted in delayed heading, flowering and maturity (Osman et al., 1981). Split application of nitrogen increased nitrogen uptake most, when the first dose are applied at sowing and second dose was applied at tillering. On the other hand, delayed applications resulted in a relatively lower uptake of nitrogen even with supplementary irrigation (Adjetey et al., 2001).

Table 7. Interaction effect of different rate and time of nitrogen application on days to heading, days to maturity and relative economic return

Interaction		**Days to Heading**	**Days to Maturity**	**Agronomic use efficiency of N ($kgkg^{-1}$)[a]**	**Relative economic return (Tk.)[a]**
Treatment A	Treatment B				
D_0	T_1	51.00 g	75.67 h	0	0
	T_2	50.67 g	74.00 i	0	0
	T_3	46.67 i	70.33 j	0	0
D_1	T_1	55.00 d	85.67 f	35	33286.50
	T_2	54.00 e	82.00 g	30.4	47624.40
	T_3	49.33 h	76.00 h	23.8	36991.80
D_2	T_1	58.67 b	94.33 b	32.7	102659.40
	T_2	56.33 c	92.67 c	30.3	94926.60
	T_3	52.67 f	91.33 d	22.8	70761.60
D_3	T_1	60.33 a	98.33 a	18.6	85843.80
	T_2	58.33 b	94.33 b	15.8	72311.40
	T_3	54.67 d	90.00 e	15.07	68767.20
CV (%)		1.76	2.07		
LSD		0.63	0.86		
Significance level		**	*		

[[a] Price of urea: 27 Tk. kg^{-1} and wheat grain: 32.2 Tk. kg^{-1}]

Mean values within the column with similar letter are not significantly ($p<0.01$) different; Where, D_0 = 0 kg N ha^{-1} (Control), D_1 = 50 kg N ha^{-1}, D_2 = 100 kg N ha^{-1} and D_3= 150 kg N ha^{-1}

T_1: 2/3rd portion of nitrogen was applied at final land preparation+1/3rd portion of nitrogen was applied at the time of first irrigation (25 DAS)

T_2: 1/3rd portion of nitrogen was applied at final land preparation+1/3rd portion of nitrogen was applied at the time of first irrigation (25 DAS) +1/3rd portion of nitrogen was used at the time of second irrigation (45 DAS)

T_3:1/2 portion of nitrogen was applied at the time of first irrigation (25 DAS) +1/2 portion was applied at second irrigation (45 DAS)

DAS = Days after sowing, CV= Co-efficient of Variation, LSD= Least Significant Difference, ***** = Significant at 5% level of significance, ****** = Significant at 1% level of significance

Interaction effects of different rates and times of nitrogen application on yield attributes of wheat

Spike length

Interaction effect of different rates and times of N application significantly affected spike length of wheat at 1% level of significance (Table 8). The longest spike (18.17 cm) was obtained from D_2T_1 whereas the shortest spike (9.76 cm) was obtained from D_0T_2 which was statistically similar to D_0T_3 (9.83 cm). These results showed that optimum dose and proper time N application influenced spike length in wheat. Similar result was obtained from Osman *et al.* (1981).

Grain spike^{-1}

Significant variation was found among the data regarding number of grain $spike^{-1}$ at 1%

level of significance due to the interaction effect of rates and times of nitrogen application on wheat (Table 8). The maximum number of grain spike^{-1} (44.33) was obtained from D_2T_1 and the minimum number of grain spike^{-1} (13.67) was obtained from D_0T_3 than the other treatments. Similar result was obtained from Iqbal et al. (2012) and Nazir et al. (2000).

Unfilled grain spike^{-1}

Number of unfilled grain spike^{-1} of wheat was significantly (p<0.01) affected by the combined effect of different rates and times of N application (Table 8). The maximum unfilled grain spike^{-1} (6.33) was obtained from D_0T_3 and the minimum unfilled grain spike^{-1} (0.67) was obtained from D_2T_2 which was statistically similar to D_2T_1 (1.00). These results showed that the unfilled grain spike^{-1} was influenced by optimum does (100 kg ha^{-1}) and time of N application. Similar result was obtained from Iqbal et al. (2012) and Nazir et al. (2000).

1000 grain weight

Interaction effect of different rates and times of N application significantly affected 1000 grain weight of wheat. Results (Table 8) showed that the highest 1000 grain weight (49.00 g) was obtained from D_2T_1 followed by D2T2. The lowest 1000 grain weight (23.63 g) was obtained from no N application (D_0T_3). Similar result was obtained from Iqbal et al. (2012) and Nazir et al. (2000).

Grain yield

Significant (P<0.01) variation was observed due to interaction effect of different rates and times of N application on wheat grain yield (Table 8). The highest grain yield (4.27 t ha^{-1}) was recorded from D_2T_1 followed by D_2T_2 (4.09 t ha^{-1}) whereas the lowest grain yield (0.75 t ha^{-1}) was obtained from D_0T_3 which was preceded by D_0T_1 and D_0T_2. It indicated that recommended dose of nitrogen (100 kg ha^{-1}) applied 2/3rd at final land preparation and 1/3rd at 25 DAT ensures better growth of plants and provides higher dry matter accumulation in the spike in this N deficient soil. Similar results were obtained from Iqbal et al. (2012) and Nazir et al. (2000).

Straw yield

Straw yield was significantly (P<0.01) affected by the combined effect of different times and rates of N application on wheat (Table 8).The highest straw yield (5.67 t ha^{-1}) was obtained from D_3T_1 which was statistically similar to D_3T_2 (5.56 t ha^{-1}), D_2T_1 (5.50 t ha^{-1}), and D_2T_2 (5.49 t ha^{-1}). The lowest straw yield (1.92 t ha^{-1}) was obtained from D_0T_1 preceded by D_0T_2 and D_0T_3. High N dose influences higher vegetative growth consequently increases straw yield in wheat. These findings are consonance with the report of Duan et al. (2014) and Nazir et al. (2000).

Harvest index

Results revealed that harvest index was significantly (p<0.01) affected by the interaction effect of different rates and times of N application on wheat (Table 8). The highest harvest index (46.12%) was obtained from D_2T_1 followed by D_2T_2 whereas the lowest harvest index (25.38%) was obtained from D_0T_3. These result showed that the harvest index was the highest with recommended N rate and applied in split giving higher dose in earlier stage (D_2T_1) and the lowest value was in the treatment without N (D_0T_3) compared to other treatments. Similar result was attained by Iqbal et al. (2012).

Nitrogen use efficiency and economic return

Agronomic N use efficiency was the highest (35 kgkg^{-1}) in D1T1followed by D2T1(32.7 kgkg^{-1}) and the highest relative economic return (102659 Tk.) was in D2T1 followed by D2T2 (94926 Tk.) treatment combinations (Table 7).

Table 8. Interaction effect of different rate and time of nitrogen application on yield and yield attributes of wheat

Interaction		Spike Length (cm)	Grain Spike^{-1}	Unfilled Grain Spike^{-1}	1000 Grain Weight (g)	Grain Yield (t ha^{-1})	Straw Yield (t ha^{-1})	Harvest Index (%)
Treatment A	Treatment B							
D_0	T_1	10.33i	16.67 g	5.00 b	25.87 g	1.00 i	1.92 e	35.23 f
	T_2	9.76 j	17.00 g	5.00 b	25.87 g	1.06 i	2.22 d	35.51 f
	T_3	9.83 j	13.67 h	6.33 a	23.63 h	0.75 j	2.30 d	25.38 h
D_1	T_1	13.60 f	36.00 c	2.67 e	38.97 e	2.75 f	4.39 c	38.96 d
	T_2	12.67 g	33.00 d	2.33 e	38.50 e	2.58 g	4.54 c	37.08 e
	T_3	12.27 h	27.33 f	4.33 c	36.50 f	1.94 h	4.99 b	30.06 g
D_2	T_1	18.17 a	44.33 a	1.00 f	49.00 a	4.27 a	5.12 b	46.12 a
	T_2	17.50 b	41.67 b	0.67 f	47.17 b	4.09 b	5.49 a	44.45 b
	T_3	17.23 c	35.67 c	2.67 e	40.40 d	3.03 e	5.50 a	35.43 f
D_3	T_1	16.33 d	35.00 c	2.33 e	43.40 c	3.79 c	5.67 a	40.06 c
	T_2	15.63 e	35.00 c	3.33 d	41.07 d	3.43 d	5.56 a	37.70 e
	T_3	15.47 f	30.00 e	3.33 d	41.03 d	3.01 e	4.20 c	35.15 f
CV (%)		2.71	8.54	28.97	3.26	7.42	7.97	3.81
LSD		0.25	1.73	0.62	0.87	0.13	0.23	0.93
Significance level		**	**	**	**	**	**	**

Mean values within the column with similar letter are not significantly ($p<0.01$) different; Where, D_0 = 0 kg N ha^{-1} (Control), D_1 = 50 kg N ha^{-1}, D_2 = 100 kg N ha^{-1} and D_3= 150 kg N ha^{-1}

T_1: 2/3rd portion of nitrogen was applied at final land preparation+1/3rd portion of nitrogen was applied at the time of first irrigation (25 DAS)

T_2: 1/3rd portion of nitrogen was applied at final land preparation+1/3rd portion of nitrogen was applied at the time of first irrigation (25 DAS) +1/3rd portion of nitrogen was used at the time of second irrigation (45 DAS)

T_3:1/2 portion of nitrogen was applied at the time of first irrigation (25 DAS) +1/2 portion was applied at second irrigation (45 DAS)

DAS = Days after sowing, CV= Co-efficient of Variation, LSD= Least Significant Difference, ***** = Significant at 5% level of significance, ****** = Significant at 1% level of significance

CONCLUSION

On the basis of present investigation, it may be concluded that high dose of N (150 kg ha^{-1}) performed best in dry matter production and growth whereas, recommended dose of N (100 kg ha^{-1}) was found best in the production of yield and yield contributing characters of wheat. In case of time of N application, 2 splits (T_1 - 2/3rd portion at final land preparation + 1/3rd portion at 25 DAS) were found superior for all the studied parameters of wheat. Growth parameters were found to be higher at 150 kg ha^{-1} (D_3) with 2 splits N application (T_1). Yield and yield contributing characters of the crop except unfilled grain spike^{-1} and straw yield were found superior with 100 kg ha^{-1} (D_2) of N application in two splits (T_1) where the highest grain yield was 4.27 t ha^{-1}. The highest straw yield (5.67 t ha^{-1}) was obtained from D_3T_1 treatment combination. Higher agronomic N use efficiency (35 kgkg^{-1}) was observed in D1T1followed by D2T1(32.7 kgkg^{-1}) and the highest relative economic return (102659 Tk.) was in D2T1 followed by D2T2 (94926 Tk.) treatment combinations. For wheat cultivation, application of recommended dose of N (100 kg ha^{-1}) in 2 splits (2/3rd portion at final land preparation + 1/3rd portion at 25 DAS) could be the optimum N application schedule in N deficit soil of south west Bangladesh.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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