British Journal of Applied Science & Technology
6(5): 497-507, 2015, Article no.BJAST.2015.105
ISSN: 2231-0843

SCIENCEDOMAIN *international*
www.sciencedomain.org

Timing of First Irrigation and Split Application of Nitrogen for Improved Grain Yield of Wheat in Old Himalayan Piedmont Plain of Bangladesh

M. A. Z. Sarker[1], Akbar Hossain[1*] and Jaime A. Teixeira da Silva[2]

[1]*Wheat Research Centre, Bangladesh Agricultural Research Institute, Dinajpur-5200, Bangladesh.*
[2]*P.O.Box 7, Miki cho post office, Ikenobe 3011-2, Kagawa-Ken, 761-0799, Japan.*

Authors' contributions

This work was carried out in collaboration between all authors. MAZS and AH conceived the experiments and experimental design. MAZS, AH and JATdS assessed and analyzed the data. MAZS, AH and JATdS wrote all drafts of the paper, approved the final draft for submission and take full public responsibility for its content. All three authors abide by and satisfy the conditions of authorship as defined by the four clauses of the ICMJE.

Article Information

DOI: 10.9734/BJAST/2015/15091
Editor(s):
(1) Hamid El-Bilali, Mediterranean Agronomic Institute of Bari (CIHEAM/IAMB), Sustainable Agriculture, Food & Rural Development Department, Italy.
(2) Ahmet Ertek, Department of Agricultural Structures and Irrigation, Suleyman Demirel University, Isaparta, Turkey.
Reviewers:
(1) Elouaer Mohamed Aymen, Department of Horticulture Sciences, High Institute of Agronomy, Tunisia.
(2) Anonymous, Mexico.
(3) Anonymous, Poland.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=768&id=5&aid=7606

Original Research Article

Received 5th November 2014
Accepted 18th December 2014
Published 3rd January 2015

ABSTRACT

Soil water and nitrogen (N) are the two most important factors in wheat for obtaining higher grain yield. In this context, a field trial was conducted at the research farm (25º38´ N, 88º41´ E and 38.20 m above sea level) of the Wheat Research Centre (WRC), Bangladesh to identify the timing of first irrigation (FI_{timing}) and its combination with a split application of N (N_{SA}) for improved yield of wheat. The treatments applied were two levels of N (75 and 100 kg ha^{-1}) and different amounts of N in splits with different application times of FI to verify the FI_{timing} in light soil and to minimize N use by rescheduling the FI. Existing wheat variety 'Prodip' was used as the experimental material. The interaction between FI_{timing} and N_{SA} on yield and yield-related components of wheat, except for 1000-grain weight, did not vary significantly. However, higher grain yield (3.39 t ha^{-1}) was obtained when the crop was irrigated at 15 days after sowing (DAS) than when irrigated latter (20, 25 and 30

**Corresponding author: E-mail: tanjimar2003@yahoo.com;*

DAS). On average, higher grain yield (3.58 t ha^{-1}) was obtained from 100 kg N ha^{-1} when it was applied half as basal and half as one top dressing than 75 kg N ha^{-1} when applied half as basal and half as one top dressing. Large grains were obtained when the FI was applied at 25 DAS in all N treatments except for 75 kg N ha^{-1} when applied half as basal at the time of final land preparation and half as top dressing, on 30 DAS in half N as basal at both levels of N and at 15 DAS when 100 kg N ha^{-1} was applied half as basal and half as top dressing. So, it is evident that the amount and split application of N with first irrigation are the most important factors determining higher grain yield and yield-related components of wheat in light soil of Bangladesh. According to our research findings, 100 kg N ha^{-1} is recommended, 1/2 as basal and 1/2 as top dressing at the time of FI at 15 or 20 DAS.

Keywords: Verification; first-irrigation; top-dress; nitrogen; wheat.

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) production in arid and semi-arid regions is constrained by many factors including high temperatures, moisture deficit and low soil fertility [1,2,3]. Among these, nitrogen (N) deficit is one of the most important due to a deficit in soil moisture. Water stress and N deficiencies reduce photosynthates because of stomatal closure and early leaf senescence [2,4], which ultimately affect processes related to grain development. The uptake and assimilation of N, a key factor to achieving optimum grain yield, are governed by various agronomic factors [5,6]. The addition of N fertilizer to wheat is required to ensure the N availability throughout the growing season, due to its important role in promoting both vegetative and reproductive growth. In particular, N plays a dominant role in various growth processes since it is an internal part of chlorophyll, a constituent of enzyme proteins and nucleic acids [2,6,7].

High temperature is also a major challenge to wheat production in arid and semi-arid regions. It reduces grain yield by altering physiological processes, accelerating vegetative growth and reducing the rate and duration of grain filling [8,9]. Ageeb [10] and Badaruddin et al. [11] reported that wheat yield in hot environments could be improved by modifying the crop micro-climate through cultural practices such as mulching, frequent irrigation and application of N fertilizer. They also reported that N fertilizers could increase, in wheat, above-ground dry matter production and grain yield by increasing leaf area index and green leaf area duration, ground cover and the area of green spikes. The application of N under heat stress significantly increased canopy temperature depression, biomass production and grain yield [11,12]. Canopy cooling in dry, heat-stressed areas is regarded as one of the most physiologically efficient ways to attain high grain yields in wheat. Twelve wheat genotypes were grown with four N levels in a two-year field trial to investigate the efficiency of adding Non canopy cooling and high chlorophyll accumulation under a dry but irrigated hot environment in Sudan [13]. The application of N fertilizer was reflected in a cooler canopy under dry heat stres, resulting in higher dry matter accumulation and grain yield, although the response was cultivar-dependent.

Previous findings showed that crops respond better to a split application of N than to a single application. For example, the growth, N uptake, and yield-related attributes of wheat were significantly higher under split (two or three) applications of N compared to N applied as a single application [14]. Timsina et al. [15] conducted a two-year field experiment in the north of Bangladesh: A split application of N resulted in better crop performance (yield and yield-related components) under irrigated than rainfed conditions.

Researchers have been looking for ways and means to increase the efficiency of N fertilizer use to increase productivity to meet the demand of increasing world populations [16]. In recent years, intensive management studies have shown that split topdressing of N fertilizer as an efficient use of N fertilizer is important for economical wheat production and to sustain the quality of ground and surface waters. Insufficient N fertilizer results in reduced wheat yield and reduced profits compared to a properly fertilized wheat crop [16]. However, excessive N produces wheat plants that are susceptible to disease, resulting in reduced yield and increased input cost. The potential for nitrate (NO_3) enrichment of ground and surface waters also increases with excessive N fertilization.

For wheat varieties developed since 1998, the Wheat Research Center (WRC) at the

Bangladesh Agricultural Research Institute (BARI) has recommended that the timing of first irrigation (FI) be 17-21 days after sowing (DAS) of seeds and that a larger amount of N be applied as basal during final land preparation [17]. There are no research findings for recommendations related to the timing of first irrigation (FI_{timing}) and its combination with the split application of N (N_{SA}) for varieties developed from 1998 to 2014. Considering these facts, this experiment was established to assess the timing of FI with different amounts of N as basal and top dressing with the sole objective of improving the grain yield of wheat.

2. MATERIALS AND METHODS

This study was conducted at the experimental field of the WRC, Bangladesh in two wheat-growing seasons (November to April, 2007-2008 and 2008-2009). The Agro Ecological Zone (AEZ) of the area is the Old Himalayan Piedmont Plain (AEZ-1). The geographical position of the area is between 25º38´ N, 88º41´ E and 38.20 m above sea level. The experimental site covers about 21% of the wheat-growing area of Bangladesh. The climate of the district is suitable due to a comparatively cooler and longer winter. However, the soil is sandy-loam and its reaction is strongly acidic (pH ranges from 4.5 to 5.5), organic matter content is less than 1%, N, K (potassium), S (sulfur), B (boron), Mg (magnesium) and Zn (zinc) was below the critical level, but P (phosphorus) was higher than the critical level, but not in a plant-available form [18]. The maximum and minimum weekly average temperatures (ºC) in the growing seasons were recorded and are presented in Fig. 1.

The experiment was laid out in split-plot design with three replications having a unit plot size of 4×5 m. Four irrigation times viz., at 15 (FI_{15DAS}), 20 (FI_{20DAS}), 25 (FI_{25DAS}) and 30 (FI_{30DAS}) days after sowing (DAS) were assigned to main plots and four amounts of N and splitting methods were assigned to sub-plots: I) T_1 =75 kg N ha^{-1} (2/3 as basal and 1/3 as top dressing); II) T_2 =75 kg N ha^{-1} (1/2 as basal and 1/2 as top dressing); III) T_3 = 100 kg N ha^{-1} (2/3 as basal and 1/3 as top dressing); IV) T_4 = 100 kg N ha^{-1} (1/2 as basal and 1/2 as top dressing). A blanket dose of P-K-S-B was applied as basal at 26-40-20-1 kg ha^{-1}.

Variety 'Prodip' is a popular variety in Bangladesh due to its attractive grain colour and size, and spike length (longest, compared to other varieties). Research finding have indicated that 'Prodip' has the potential to produce higher yield under optimum conditions, although it is sensitive to early and late heat stress [19]. On the other hand, Badaruddin et al. [11] reported that wheat yield in hot environments could be improved by modifying the crop's micro-climate through cultural practices such as mulching, frequent irrigation and the application of N fertilizer. Considering this information, 'Prodip' was used to better assess and quantify its yield potentiality. 'Prodip' seeds treated with Provax-200 were sown at 140 kg ha^{-1} on 22 November 2008. Provax-200 WP (seed-treated fungicide) contains Carboxin and Thiram. Research at the WRC [20] indicates that Provax-200 WP is a perfect match for controlling fungi in Bangladesh soil, for achieving excellent seed germination and for protecting wheat cultivars from fungal attacks during the seedling stage.

All N top dressings were applied once after FI in accordance with the main plot treatments. Second irrigation was applied at 51, 54, 61 and 63 DAS, and third irrigation was applied at 72, 74, 78 and 80 DAS in plots where FI was applied at 15, 20, 25 and 30 DAS, respectively. On plots where FI was applied at 15 DAS, another essential irrigation was applied at 82 DAS due to deficit soil moisture (data not shown). At the time of first, second and third irrigation, we applied only 0.0835 m or 8.35 cm water in 20 m^2 size plot. Treatment of the experiment was timing of first irrigation with split application of N. So, we only measured soil moisture immediately before all of the first irrigated plots. Soil moisture varied 12-14% before first irrigation. We calculated amount of irrigation water by following way:

$$\text{Irrigation water per plot} = \frac{\text{Irrigation meter reading}}{\text{Area under irrigated}}$$

$$\text{Irrigation needed for } 20\ m^2 = 1.67\ m^3/20\ m^2$$
$$= 0.0835\ m \text{ or } 8.35\ cm$$

Other intercultural operations were conducted in accordance with the recommendation of the WRC by considering soil moisture.

The crop was harvested plot-wise at full maturity. The sampled plants were harvested separately. Yield-related attributes were recorded after harvesting (124 DAS). The plots were harvested in strips 3 m long by using 10 (3×2 m) middle rows in all replications to avoid a border effect. The harvested crop of each plot was bundled separately, tagged and threshed in threshing floor. The bundles were thoroughly dried in bright sunshine before their weights were recorded. Data were recorded for number of spikes m^{-2} (NS), plant height (PH) (cm), spike length (SL) (cm), number of spikelets $spike^{-1}$ (NSS), number of grains $spike^{-1}$ (NGS), 1000-grain weight (1000-GW) (g), grain yield (GY) (t ha^{-1}), straw yield (SY) (t ha^{-1}) and harvest index (HI) (%). HI was calculated according to the following equation [21]:

$$\text{HI (\%)} = \frac{\text{Grain yield}}{\text{Grain yield+Straw Yield}} \times 100$$

Data collected during this study was statistically analyzed using MSTAT statistical package of Michigan State University, USA [22]. Duncan's new multiple range test (DNMRT) at $P< 0.05$ was used to test the differences between means [23].

3. RESULTS AND DISCUSSION

3.1 Weather Conditions in Experimental Period

Fluctuations in weather conditions affect crop growth and development and ultimately yield. Weather parameters such as maximum and minimum air and soil temperature, rainfall and relative humidity are the most important climatic factors for the growth and development of plants, especially in areas of dry land cultivation. The ideal timing for sowing a crop is linked to favorable climatic conditions. In this study, the wheat crop was sown on 22 November based on findings by Hossain et al. [19], Hossain et al. [24] and Hakim et al. [25], Hossain and Teixeira da Silva [26], who reported optimum sowing time for existing wheat varieties of Bangladesh, is mid-November to the first week of December. The weather conditions in our experimental period were suitable for good yield (Fig. 1) since, in the vegetative stage, average temperature was below 25ºC and at the grain-filling stage average temperature was below 20ºC, which are suitable conditions for good yield in a wheat crop. Wang et al. [27] evaluated wheat var. 'Yang 9' in Nanjing, China. The plants were divided into two batches. One batch of plants was subjected to high temperature acclimation at a day/night temperature of 32/28ºC in one growth chamber for two days while another batch was moved into another growth chamber at a day/night temperature of 24/20ºC as the non-acclimated treatment. At the same time, the remaining plants were moved to another chamber with a temperature regime of 26/22ºC as the control. Results of the study indicated that pre-anthesis high temperature acclimation alleviated the negative effects of post-anthesis heat stress on stem-stored carbohydrate remobilization and grain starch accumulation, which ultimately affected grain yield.

3.2 Yield and Yield-related Components of Wheat

Yield and yield-related components of wheat are considerably increased by increasing the level of N [28]. GY is a complex trait and is greatly influenced by many genetic factors and environmental fluctuations. Khan et al. [29] reported in rice that GY $plant^{-1}$ was positively correlated and varied significantly with PH, SL, flag leaf area and NGS. Latiri-Soki et al. [30] reported that irrigation and N increased dry matter production and GY, possibly due to increased leaf area index (LAI), area of green spikes and an increase in the period in which the crop remained green which resulted in increased capture efficiency of radiation energy and consequently more dry matter production. The responses of a crop to N fertilizer are directly related to the status of soil moisture [31,32].

3.3 Effect on Number of Spikes m^{-2}

NS is one of the major components of GY in wheat. Matsunaka et al. [33] reported an increase in GY of wheat as NS per unit area increased. NS of wheat depends on several factors such as inherent characters, environmental factors, irrigation frequency and timing, and balanced fertilizers, among them the times and frequency of irrigation being the most important. Waraich et al. [34] reported that FI at the tillering stage increased the number of tillers, ultimately increasing the NS, and resulting in 69% higher GY than the second (54%) and third irrigation (16%). Even though three irrigations could increase GY, FI is the most important one. In our experiment, higher NS was obtained from FI_{15DAS} and lower NS from FI_{25DAS} (Table 1). N supplementation had a positive effect on crop productivity, and therefore higher NS was observed in plots where N was applied. The increase in NS with the rate of N is in agreement with the findings of Melaj et al. [35] and Mandal et al. [36], who also reported that when N was applied as split doses, it increased NS more than a single dose of N applied either early or late. On the other hand, N_{SA} in different methods significantly influenced NS. On average, higher NS was found in T_4, which was statistically similar to T_3 and T_1 (Table 1). The interaction effect of FI_{timing} and N_{SA} were not significantly influenced by NS, but higher NS was recorded in T_4 with FI_{15DAS} (Table 1). Waraich et al. [34] found an identical trend.

3.4 Plant Height at Maturity

Khan et al. [29] reported that PH was positively and significantly associated with all morphological traits at the genetic level. The interaction effect and N_{SA} were not significantly different but FI_{timing} was significantly affected. Higher PH at maturity was recorded at $FI_{15\,DAS}$ in T_4 and lowest PH at FI_{30DAS} in T_3 (Table 1). Ali et al. [37] also found that wheat cv. 'Bakhar-2000' produced significantly more and taller plants throughout crop growth and that each increase in N increased PH significantly with significantly more tillers and fertile tillers when N was applied at 210 kg ha^{-1}. In their study, 'Bakhar-2000' produced higher 1000-GW and GY than 'Inqlab-91'.

3.5 Spike Length

In our study, FI_{timing} and its interaction with N_{SA} did not significantly influence SL (Table 1). Longer spikes were found in T_4 with FI_{20DAS} than in T_3 with FI_{30DAS}. On the other hand, N_{SA} was significantly influenced. Longest spikes were found in T_4 and three other treatments (T_1, T_2 and T_3) but differences were not significant (Table 1). In contrast, GY $plant^{-1}$ was highly significantly positively correlated with NS $plant^{-1}$, NSS, NGS and SL [38].

3.6 Number of Spikelets $Spike^{-1}$

In the present study, increasing levels of N fertilizer (100 kg N ha^{-1}) improved GY compared to a low level of N, which seems to be the result of enhanced NSS (Table 2). The increase in NSS might be caused by the efficient use of N under appropriate irrigation time. In the case of the single effect of N, the highest value was recorded in T_4 (Table 2). When growing wheat for two years at different rates of spring-applied N (0, 45, 90, and 135 kg N ha^{-1}) under irrigated and non-irrigated conditions, leaf area and photosynthetic activity during the grain-filling stage increased with increased spring N under irrigated conditions, but decreased under non-irrigated conditions [39]. Waraich et al. [34] noticed that GY and all primary yield components increased linearly in response to irrigation and N in two consecutive years. They also reported that GY, NS, NGS and 1000-GW responses were greater at higher N rates. Mean GY in 4, 3 and 2 irrigation treatments compared with that in a single irrigation treatment increased by 47, 23 and 9% in the first year and by 91, 84 and 23% in second year, respectively.

3.7 Number of Grains $Spike^{-1}$

NGS plays a vital role in GY [40,41]. Dokuyucu and Akkaya [42] also found a positive effect between NGS and GY in Turkish wheat genotypes. In our experiment, FI_{timing} and interaction effects did not significantly influence NGS, but N_{SA} was significantly influenced. This might be related to the genetic makeup of this variety, an assumption supported by Schwarte et al. [43], who stated that the NGS is determined at the panicle primordial formation stage, which is strongly dependent on genetic factors rather than management factors. On the other hand, under field observation, Rahman et al. [44] stated that in severe boron-deficient soil, partial or complete spike sterility might occur, resulting in lower NGS. In our experiment, higher NGS was found FI_{20DAS} in T_4 and statistically similar results were found in terms of the amount of N and its split application, except for T_2 as top dressing. However, highest NGS was found in T_4 (Table 2). The increase in NGS is similar to that observed by Mandal et al. [36], who stated from a three-year field experiment that increasing production of wheat from a limited water supply can result from efficient irrigation and nutrient management. They also noticed that the highest GY and seasonal ET increased significantly with an increase in water supply in every nutrient treatment, being highest in three irrigations (CRI, maximum tillering and flowering stage) with 100% NPK + farmyard manure (FYM-10 t ha^{-1}) (I_2F_2) and lowest in I_0F_0 (i.e., without fertilizers and irrigation).

3.8 1000-grain Weight

1000-GW is the most important parameter for final GY. This assumption is also supported by other researchers who stated that GY was significantly and positively correlated with 1000-GW and NS [45]. In our present study, 1000-GW was significantly influenced by the interaction effect of FI_{timing} in combination with N_{SA} (Table 2). The highest 1000-GW was found at $FI_{15\,DAS}$ in T_4, statistically followed by FI_{30DAS} in T_2, FI_{25DAS} in T_1,

FI_{25DAS} in T_3, FI_{30DAS} in T_4 and FI_{25DAS} in T_4 (Table 2). Rahman et al. [46] conducted a field experiment in Bangladesh with three doses of N (80, 100, and 120 N $kgha^{-1}$) in the form of urea, which were assigned as the main plots and four methods of N splitting (*viz.*, application of all N as basal; 2/3 basal + 1/3 as top dress at the crown root initiation (CR1) stage; 1/2 basal + 1/2 as top dress at the CR1 stage; 1/3 basal + 1/3 as top dress at CR1 + 1/3 as top dress at the first node stage) which were tested in the sub-plots. Higher yield was achieved when N was applied at 120 kg ha^{-1} as three equal splits of 1/3 as basal during final land preparation, 1/3 as top dressing during CR1 and the remaining1/3 as top dressing at the first node stage.

3.9 Harvest Index

HI is defined as the percentage grain in the total plant biomass. Genetic improvement of GY in wheat is closely associated with increases in HI, but not with increases in total biomass [47]. In our present experiment, only N_{SA} significantly influenced HI. The highest HI was found in T_4 (Table 3). The three other treatments showed the lowest values and were not significantly different to each other. On the other hand, higher HI (42.22) was found at FI_{25DAS} in T_4. A similar result was observed by Waraich et al. [34], who conducted a two-year experiment, with four irrigation levels i.e., one irrigation (irrigation at the tillering stage), two irrigations (irrigations at tillering and anthesis stages), three irrigations (irrigations at tillering, anthesis and grain development stages), four irrigations (irrigations at tillering, stem elongation, anthesis and grain development stages) and four N levels i.e., 0, 50, 100 and 150 kg N ha^{-1} were tested in Pakistan. They revealed from their study that GY and all primary yield components increased linearly in response to irrigation and N in both seasons.

3.10 Straw Yield

The interaction of FI_{timing}, N_{SA} and the single effect of FI_{timing} did not significantly influence SY. However, the single effect of N_{SA} did significantly influence this trait. A higher SY was recorded in T_4 which was statistically at par with T_3 and T_2. Significantly lower SY was observed in T_1 (Table 3). A similar result to our study was reported by Afridi et al. [48], who stated that, compared to the control, N level increased NS, NGS, 1000-GW, GY and SY. Similarly, the split application of N improved NS, NGS, GY and SY more than the control, whereas 1000-GW and HI were not affected by N_{SA}.

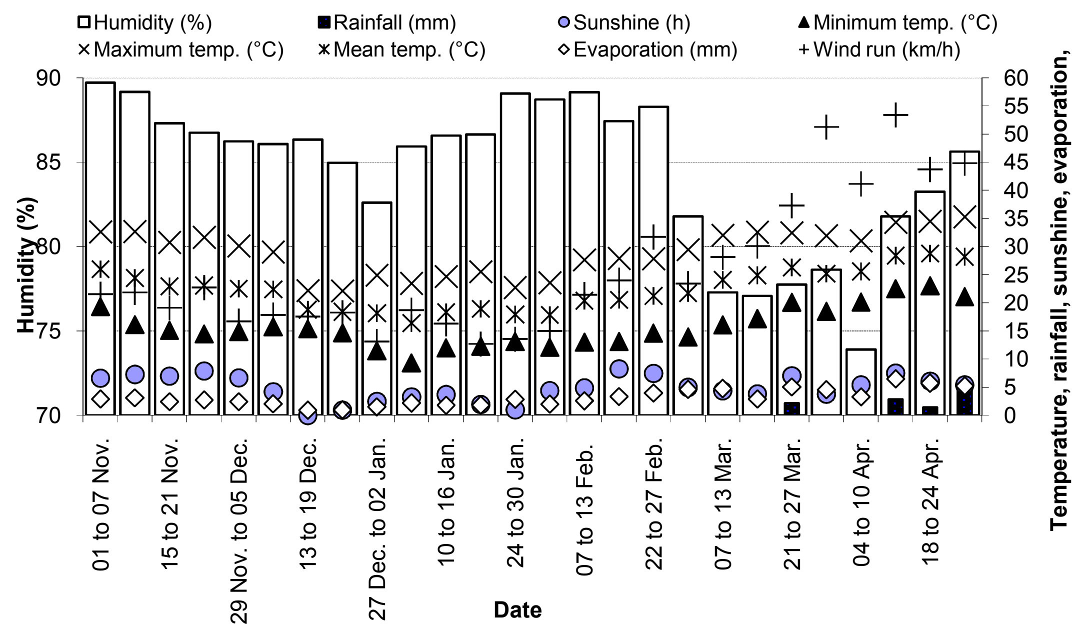

Fig. 1. Weather information during the wheat growing period (Source: Meteorological Station, Wheat Research Centre, Nashipur, Dinajpur, Bangladesh)

Table 1. Spikes m^{-2}, plant height and spike length of wheat as influenced by time of first irrigation, amount and splitting application methods of nitrogen. 1st irrigation at 15 DAS = FI_{15DAS}, 1st irrigation at 20 DAS = FI_{20DAS}, 1st irrigation at 25 DAS = FI_{25DAS}, 1st irrigation at 30 DAS = FI_{30DAS}; T1 = 75 kg N ha^{-1} (2/3 as basal and 1/3 as top dressing), T2 = 75 kg N ha^{-1} (1/2 as basal and 1/2 as top dressing), T3 = 100 kg N ha^{-1} (2/3 as basal and 1/3 as top dressing), T4 = 100 kg N ha^{-1} (1/2 as basal and 1/2 as top dressing)

Treatments	T_1	T_2	T_3	T_4	Mean	CV (%) (Irrigation)
			Number of spikes m^{-2}			
FI_{15DAS}	182	173	173	194	180	
FI_{20DAS}	180	169	177	181	177	
FI_{25DAS}	168	175	176	176	174	13.20
FI_{30DAS}	175	170	182	184	177	
Mean	176 AB	172 B	177 AB	184 A		
CV (%)(N and interaction)	**5.23**					
			Plant height (cm) at maturity			
FI_{15DAS}	97.67	97.40	97.75	98.04	97.71 A	
FI_{20DAS}	96.25	96.50	95.98	95.96	96.17 A	
FI_{25DAS}	97.80	95.26	94.87	97.24	96.29 A	1.86
FI_{30DAS}	93.00	93.19	92.54	94.73	93.36 B	
Mean	96.18	95.59	95.28	96.49		
CV (%) (N and interaction)	**1.67**					
			Spike length (cm)			
FI_{15DAS}	12.64	13.11	13.31	13.82	13.22	
FI_{20DAS}	12.64	12.72	13.04	14.59	13.25	
FI_{25DAS}	12.99	12.65	12.67	13.49	12.95	4.51
FI_{30DAS}	13.27	13.66	12.40	14.25	13.39	
Mean	12.89 B	13.04 B	12.86 B	14.04 A		
CV (%) (N and interaction)	**5.11**					

Within each trait, means followed by the same lower-case letter(s) in a column or in a row followed by the same capital letter(s) indicate significant differences (P ≤ 0.05) according to DMRT

Table 2. Spikelets $spike^{-1}$, grains $spike^{-1}$ and 1000-grain weight of wheat as influenced by the timing of first irrigation, amount and splitting application methods of nitrogen. Treatment details are as for Table 1

Treatments	T_1	T_2	T_3	T_4	Mean	CV (%) (Irrigation)
			Spikelets $spike^{-1}$ (no.)			
FI_{15DAS}	19.17	19.03	18.50	20.70	19.35	
FI_{20DAS}	19.50	18.73	18.90	19.73	19.22	
FI_{25DAS}	19.63	17.70	19.00	20.63	19.24	4.14
FI_{30DAS}	18.87	20.00	18.67	20.70	19.56	
Mean	19.29 B	18.87 B	18.77 B	20.44 A		
CV (%) (N and interaction)	**3.80**					
			Grains $spike^{-1}$ (no.)			
FI_{15DAS}	42.00	41.70	45.70	45.10	43.60	
FI_{20DAS}	44.80	41.30	46.30	47.20	44.90	
FI_{25DAS}	45.40	41.50	44.20	44.60	43.90	5.76
FI_{30DAS}	42.80	46.90	45.30	45.10	45.00	
Mean	43.80AB	42.80 B	45.40 A	45.5 A		
CV (%) (N and interaction)	**5.33**					
			1000-grain weight (g)			
FI_{15DAS}	57.8 bc	57.7 bcd	56.9 bcd	60.3 a	58.2	
FI_{20DAS}	57.5 bcd	57.3 bcd	55.3 d	56.0 cd	56.5	
FI_{25DAS}	59.3 ab	57.7 bcd	59.1 ab	58.3 abc	58.6	3.63
FI_{30DAS}	57.0 bcd	60.1 a	56.4 cd	58.8 ab	58.1	
Mean	57.9 AB	58.2 A	56.9 B	58.4 A		
CV (%)(N and interaction)	**2.16**					

Within each trait, means followed by the same lower-case letter(s) in a column or in a row followed by the same capital letter(s) indicate significant differences (P ≤ 0.05) according to DMRT

Table 3. Harvest index, straw yield and grain yield of wheat as influenced by time of first irrigation, amount and splitting application methods of nitrogen. Treatment details are as for Table 1

Treatments	T_1	T_2	T_3	T_4	Mean	CV (%) (Irrigation)
			Harvest index (%)			
FI_{15DAS}	40.05	39.82	39.17	40.16	39.80	
FI_{20DAS}	39.54	39.55	38.63	41.87	39.90	
FI_{25DAS}	39.75	37.78	38.95	42.22	39.68	5.17
FI_{30DAS}	38.48	40.43	40.26	41.46	40.16	
Mean	39.46 B	39.39 B	39.25 B	41.43 A		
CV (%) (N and interaction)	**3.68**					
			Straw yield (t ha^{-1})			
FI_{15DAS}	4.91	4.69	5.18	5.10	4.97	
FI_{20DAS}	4.89	4.70	5.09	5.01	4.92	
FI_{25DAS}	4.79	4.70	4.92	5.21	4.90	10.74
FI_{30DAS}	5.31	4.50	4.85	5.26	4.98	
Mean	4.97 AB	4.65 B	5.01 A	5.14 A		
CV (%) (N and interaction)	**7.99**					
			Grain yield (t ha^{-1})			
FI_{15DAS}	3.27	3.10	3.52	3.65	3.39	
FI_{20DAS}	3.20	3.08	3.19	3.58	3.26	
FI_{25DAS}	3.16	2.85	3.37	3.52	3.22	6.69
FI_{30DAS}	3.10	2.96	3.27	3.57	3.23	
Mean	3.18 C	3.00 D	3.34 B	3.58 A		
CV (%) (N and interaction)	**5.35**					

Within each trait, means followed by the same lower-case letter(s) in a column or in a row followed by the same capital letter(s) indicate significant differences (P ≤ 0.05) according to DMRT

3.11 Grain Yield

On average, higher GY was obtained from FI_{15DAS} plots. Since FI was applied earlier, these plots also needed irrigation earlier than when FI was applied later. These plots also needed irrigation more during the grain-filling stage (82 DAS). This may have consequently increased grain size with a subsequent higher GY in these plots. Roy and Pandit [49] reported FI at crown root initiation stage (15-21 DAS) increased wheat GY by 43% more than the non-irrigated crop. Rahman et al. [50] also reported that irrigation at an early growth stage (18-21 DAS) of wheat increased GY compared to other irrigation treatments. Waraich et al. [34] reported that irrigation at the tillering stage increased GY 69% more than irrigation at anthesis (54%) and grain-filling (16%) stages.

Compared to all FI_{timing} and amounts of N_{SA}, higher GY was recorded for all FI_{timing} in T_4. FI_{15DAS} was highest followed by FI_{20DAS}, FI_{30DAS} and FI_{25DAS}. A lower GY was obtained by FI_{25DAS} in T_2. On average, significantly higher GY was obtained in T_4 than in T_3. T_1 and T_2 treatments always produced significantly lower GY than T_3 and T_4. Significantly lower GY was observed in T_2 than in T_1 (Table 3).

Therefore, in wheat, N is more essential in early growth stages. For this reason, 1/2 N of 75 kg ha^{-1} as basal was not enough for producing optimum NS, SL, NSS, NGS and HI for higher GY. Using 2/3 N of 75 kg ha^{-1} as basal might increase NS, SL, NSS, HI, which is similar to an application of 100 kg N ha^{-1}. Half the amount of N (i.e., 50 kg N ha^{-1}) as basal is enough for producing optimum NS and a slightly higher amount of N (1/2) than 1/3 N (i.e., 33.34 kg ha^{-1}) of 100 kg N ha^{-1} as top dressing might have had an additive effect on GY in light soil (sandy loam) in our experimental site (Table 3).

Gorjanovic et al. [51] conducted an experiment to investigate variability of GY of 12 bread wheat genotypes using three N levels (0, 75 and 100 kg ha^{-1}). In all three levels, the highest GY was found in var. 'Malyska' while the lowest GY in the control was found in var. 'Nevesinjka', while in the N_{75} and N_{100} rates it was found in var. 'Tamaro'.

4. CONCLUSION

From the results and discussion of our study, it is evident that the amount and split application of N with first irrigation are the most important factors determining higher grain yield and yield-related components of wheat. According to our research findings, 100 kg N ha^{-1} is recommended, 1/2 as basal and 1/2 as top dressing at the time of FI at 15 or 20 DAS.

ACKNOWLEDGEMENT

The authors acknowledge the efforts of all field staff in Agronomy division of WRC for their technical assistance during experimentation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. El-Siddig K, Lüdders P, Ebert G, Diku SGK. Response of rose apple (*Eugenia jambos* L.) to water and nitrogen supply. J. Appl. Bot. 1998;72:203–206.
2. Chauhan BS, Mahajan G, Sardana V, Timsina J, Jat ML. Productivity and sustainability of the rice-wheat cropping system in the indo-Gangetic plains of the Indian subcontinent: Problems, opportunities, and strategies. Adv. Agron. 2012;117:316–355.
3. Balasubramanian V, Adhya TK, Ladha JK. Enhancing eco-efficiency in the intensive cereal-based systems of the Indo-Gangetic Plains. In: Issues in Tropical Agriculture Eco-Efficiency: From Vision to Reality. CIAT Publication, Cali, CO; 2012.
4. Singh U, Wilkens PW. Simulating water and nutrient stress effects on phonological development in maize. Field Crops Res. 1999;44:1–5.
5. Power JF, Secheepers JS. Nitrate contamination of ground water in North America. Agri. Ecosyst. Environ. 1989;26: 165–187.
6. Timsina J, Quayyum MA, Connor DJ, Saleque M, Haq F, Panaullah GM, Jahan MAHS, Begum RA. Effect of fertilizer and mungbean residue management on total productivity, soil fertility, N-use efficiency of intensified rice-wheat systems. Int. J. Agric. Res. 2006;1(1):41–52.
7. Marschner P. Marschner's: Mineral nutrition of higher plants. Third edition, Academic Press Inc., San Diego. USA. 2011;672 .
8. Wardlaw IF, Moncur L. The response of wheat to high temperature following anthesis: I. The rate and duration of kernel filling. Aust. J. Plant Physiol. 1995;22: 391–397.
9. Tahir ISA, Nakata N, Ali AM, Mustafa HM, Saad ASI, Takata K, Ishikawa N, Abdalla OS. Genotypic and temperature effects on wheat grain yield and quality in a hot-irrigated environment. Plant Breed. 2006;125: 323–330.
10. Ageeb OAA. Agronomic aspects of wheat production in Sudan. *In* Saunders DA and GP. Hettel (eds.) Wheat in Heat-Stressed Environments: Irrigated, Dry Areas and Rice-Wheat Farming Systems. CIMMYT, Mexico, DF. 1994;67–74.
11. Badaruddin M, Reynolds MP, Ageeb OAA. Wheat management in warm environments: Effect of organic and inorganic fertilizers, irrigation frequency, and mulching. Agron. J. 1999;91:975–983.
12. Ali ZI. Morph-physiological traits associated with moisture and nitrogen stresses in some wheat (*Triticum aestivum* L.) genotypes. PhD thesis. Gezira University, Sudan. 2000;123.
13. Elbashier EME, Tahir ISA, Saad ASI, Ibrahim MAS. Wheat genotypic variability in utilizing nitrogen fertilizer for a cooler canopy under a heat-stressed irrigated environment. African J. Agric. Res. 2012;7(3):385–392.
14. Bhardwaj V, Vijay V, Yadav V, Chauhan BS. Effect of nitrogen application timings and varieties on growth and yield of wheat grown on raised beds. Arch. Agron. Soil Sci. 2010;56:211–222.
15. Timsina J, Singh U, Badaruddin M, Meisner CA, Amin MR. Cultivar, nitrogen, and water effects on productivity and nitrogen use efficiency and balance for rice-wheat sequences of Bangladesh. Field Crops Res. 2001;72:143–161.
16. Ramu N. Nitrogen management in wheat under irrigated conditions. M.S thesis, Dept. Agronomy, College of Agriculture, Dharwad University of Agricultural Sciences. 2008. (Last accessed: 4 January, 2015) Available online at: http://etd.uasd.edu/ft/th9819.pdf
17. WRC (Wheat Research Centre). Wheat Research Centre. Gom Uthpadon O Beej Songrakkhon (Wheat Production and Seed Preservation). Training Manual. Wheat production and seed preservation. WRC, BARI, Dinajpur. (In Bangla). 2007;24.
18. Bodruzzaman M, Lauren JG, Duxbury JM, Sadat MA, Welch RM, Elahi NE, Meisner

CA. Increasing wheat and rice productivity in the sub-tropics using micronutrient enriched seed. In: Anderson P, Junoo K, Tuladhar B. Krishna, Karki, Surya L. Maskey (eds.) Micronutrients in South and South-east Asia. Proceedings of an International Workshop. Kathmandu, Nepal. 2004;2005:187–198.
19. Hossain A, Teixeira da Silva JA, Lozovskaya MV, Zvolinsky VP. The effect of high temperature stress on the phenology, growth and yield of five wheat (*Triticum aestivum* L.) genotypes. Asian Australasian J. Plant Sci. Biotech. 2012;6(1):14–23.
20. WRC (Wheat Research Centre). Annual report 2008-09, Wheat Research Centre, Bangladesh. 2009;181.
21. Donald CM. In search of yield. J. Austr. Inst. Agric. Sci. 1962;238:171–178.
22. Anonymous. MSTAT Micro-Computer Statistical Programme. Michigan State University. East Lansing, Michigan, USA; 1986.
23. Steel RGD, Torrie JH. Principles and Procedures of Statistics: A Biometrical Approach. 2nd Ed., McGraw Hill Book Co. Inc., Singapore. 1984;172–177.
24. Hossain A, Sarker MAZ, Saifuzzaman M, Akhter MM, Mandal MSN. Effect of sowing dates on yield of wheat varieties and lines developed since 1998. Bangladesh J. Progress. Sci. Tech. 2009;7(1):5–8.
25. Hakim MA, Hossain A,Teixeira da Silva JA, Zvolinsky VP, Khan MM. Yield, protein and starch content of 20 wheat (*Triticum aestivum* L.) genotypes exposed to high temperature under late sowing conditions. J Sci. Res. 2012;4(2):477–489.
26. Hossain A, Teixeira da Silva JA. Phenology, growth and yield of three wheat (*Triticum aestivum* L.) varieties as affected by high temperature stress. Not. Sci. Biol. 2012;4(3):97–106.
27. Wang X, Cai J, Liu F, Jin M, Yu H, Jiang D, Wollenweber B, Dai T, Cao W. Pre-anthesis high temperature acclimation alleviates the negative effects of post-anthesis heat stress on stem stored carbohydrates remobilization and grain starch accumulation in wheat. J. Cereal Sci. 2012;55(3):331–336.
28. Basar H, Tumsavas Z, Katkat AV, Ozgumus A. Effect of nitrogen sources and rate on the yield and yield-related components yield-related components of the wheat cultivars. Turkish J. Agric. For. 1998;22:59–63.
29. Khan AS, Imran M, Asufaq M. Estimation of genetic variability and correlation for grain yield-related components of rice. American-EurasianJ. Agric. Environ. Sci. 2009;6(5):585–590.
30. Latiri-Soki K, Noitclitt S, Lawlor DW. Nitrogen fertilizer can increase dry matter, grain production and radiation and water use efficiency for durum wheat under semi-arid conditions. Eur. J. Agron. 1998;9(1):21–34.
31. Ryan JM, Abdel MM, Mergoum M, El-Gharous M. Comparative triticale and barley responses to nitrogen under varying rainfall locations in Morocco's dryland zone. Rachis. 1991;10(2):3–7.
32. Pala M, Matar A, Mazid A. Assessment of the effect of environmental factors on the response of wheat to fertilizer in on-farm trials in a Mediterranean type environment. Expt. Agric. 1996;32: 339–349.
33. Matsunaka T, Takeuchi H, Miyawaki T. Optimum irrigation period for grain production in spring wheat. Soil Sci. Plant Nutr. 1992;38(2):269–279.
34. Waraich EA, Ahmad R, Anser A, Saif U. Irrigation and nitrogen effects on grain development and yield in wheat (*Triticum aestivum* L.). Pak. J. Bot. 2007;39(5):1663–1672.
35. Melaj MA, Echeverrya HE, Lopez SC, Studdert G. Timing of nitrogen fertilization in wheat under conventional and no-tillage system. Agron. J. 2003;95:1525–1531.
36. Mandal KG, Hati KM, Misra AK, Bandyopadhyay KK, Mohanty M. Irrigation and nutrient effects on growth and water–yield relationship of wheat (*Triticum aestivum* L.) in central India. J. Agron. Crop Sci. 2005;91:416–425.
37. Ali H, Ahmad S, Ali H, Hassan FS. Impact of nitrogen application on growth and productivity of wheat (*Triticum aestivum* L.). J. Agricul. Social Sci. 2005;1:216–218.
38. Yousaf A, Babar MA, Javed A, Philippe M, Zahid L. Genetic variability, association and diversity studies in wheat (*Triticum aestivum* L.) germplasm. Pak. J. Bot. 2008;40(5):2087–2097.
39. Frederick JR, Camberato JJ. Water and nitrogen effects on winter wheat in the southeastern coastal plain: II-Physiological responses. Agron. J. 1995;4:241–248.

40. Abbate PE, Andrade FH, Lazaro L, Bariffi JH, Berardocco HG, Inza VH, Marturano F, Bariffi HF. Grain yield increase in recent argentine wheat cultivars. Crop Sci. 1998;38:1203–1209.
41. Guarda G, Padovan S, Delogu G. Grain yield, nitrogen-use efficiency and baking quality of old and modern Italian bread-wheat cultivars grown at different nitrogen levels. Eur. J. Agron. 2004;21:181–192.
42. Dokuyucu T, Akkaya A. Path coefficient analysis and correlation of grain yield and yield-related components yield-related components of wheat (*Triticum aestivum* L.) genotypes. Rachis Newslett. 1999;18:17–20.
43. Schwarte AJ, Gibson LR, Karlen DL, Dixon PM, Lieman M, Jannink JL. Planting date effects on winter triticale yield and yield-related components. Crop Sci. 2006;46(3):1218–1224.
44. Rahman MA, Karim AJMS, Shaheed MA, Samad MA. A study on the effect of irrigation and nitrogen fertilization on uptake and efficiency of nitrogen in wheat. Bangladesh J. Agric. Res. 2000;25(4):578–583.
45. Korkut KZ, Baser I, Bilgin O. Genotypic and phenotypic variability, heritability and phenotypic correlation for yield and yield-related components yield-related components in bread wheat varieties. Acta Agron Hung. 2001;49(3):237–242.
46. Rahman MA, Sarker MAZ, Amin MF, Jahan AHMS, Akhter MM. Yield response and nitrogen use efficiency of wheat under different doses and split application of nitrogen fertilizer. J. Agric. Res. 2011;36(2):231–240.
47. Slafer GA, Andrade FH. Changes in physiological attributes of the dry matter economy of bread wheat (*Triticum aestivum* L.) through genetic improvement of grain yield potential at different regions of the world. Euphytica. 1991;58:37–49.
48. Afridi MZ, Jan MT, Arif M, Jan A. Wheat yielding components response to different levels of fertilizer-N application time and decapitation stress. Sarhad J. Agric. 2010;26:499–506.
49. Roy KC, Pandit KC. Wheat technology transfer for increasing yield. A key note paper presented at the workshop on “Wheat Technology Transfer for Increasing Yield” held on Wheat Research Centre, Nashipur, Dinajpur; 2007.
50. Rahman MA, Karim AJMS, Solaiman ARM, Haque MM, Saifuddin KM. Water use, yield and yield-related of wheat under irrigation and nitrogen application in terrace soil of Bangladesh. Ann. Bangladesh Agric. 1999;9(2):191–204.
51. Gorjanovic B, Zoric M, Kraljevic BM. Effect of nitrogen rate on grain yield of bread wheat genotypes. Genetika. 2010; 42(2):279–286.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=768&id=5&aid=7606